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Educational Games to Enhance Museum Visits for Schools

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ABSTRACT

Museums usually look for new educational tools to enhance their exhibition. The Oteiza's museum in Navarre (Spain) especially gives importance to the dissemination of Jorge Oteiza's work to children at schools. Consequently, a didactics section was created with the objective of developing activities and relationship with schools. Jorge Oteiza represents one of the most important artists in the Spanish modern art and his sculptures stem from his proper philosophical concepts such as negative aesthetics via addition and subtraction, or activation of space and time. Such notions make the learning process at school complex. Thus, this study proposes a framework that aims to enhance the visit to the museum through a series of mini-games that shed light on these abstract concepts. Representative sculptures were selected and the corresponding activities were designed and developed in collaboration with the didactics section of the museum following a Co-Design approach. Then, the framework was tested by pupils from primary and secondary schools and students from educational practice. Therefore this paper provides a guideline to design educational games in collaboration with a museum, shows that mini educational games help students in learning artistic concepts and that motion-based touchless interfaces are not really adapted for classroom use.

Keywords

Virtual Reality, Museum, Interactive Learning Environments, Human-Computer Interface, Media in Education

Introduction

Museums acquire, conserve, research, communicate and exhibit cultural heritage for the purposes of education, study and enjoyment (ICOM, 2007). These institutions mostly target specialists, tourists and students (Bowen & Filippini-Fantoni, 2004) and thus, are usually looking forward to engaging their public in new types of displays in order to understand and appreciate the cultural heritage (Petridis et al., 2013). Museums do not limit their interests to indoor exhibits but also to the dissemination of the cultural heritage (Paliokas & Kekkeris, 2008). For instance, it has been shown that a clear learning strategy between schools and museums reinforce students' learning experience (Griffin, 2004). The relationship between the entities can be strong with the creation of teamworks (students, educators, museum staff and researchers) which objective is usually to conceive specific museum activities (Wishart & Triggs, 2010). Such projects have shown interesting results, but it implies an additional cost for the schools and the stakeholders' time schedule might invade their personal time (Vavoula et al., 2009). Another type of collaboration, which is not as strong as the abovementioned one, is the development of virtual museum applications specifically designed to be used at school (Paliokas & Kekkeris, 2008).

With such an objective, the Oteiza's museum in Navarre (Spain), made a call for a project to disseminate Jorge Oteiza's work at schools. This project, "Oteiza para tod@s" (literally, Oteiza for all), answered this call by proposing a framework that integrates the three following components: Art, Education and Technology. Jorge Oteiza represents one of the most important artists in the Spanish modern art (Alvarez-Martinez, 2003; Pelay, 1978). His sculptures move from at the vanguard art such as cubism or constructivism to his proper mathematical / philosophical concepts such as negative aesthetics (Alvarez-Martinez, 2003; Echeverria-Plazaola, 2012). Such concepts make the learning process at school complex and this is what motivates the didactics section of Oteiza's museum to look for new educational tools (Urtasun, 2006).

Literature review

The "2015 Innovating Pedagogy report" pointed out that "*crossover learning"* would be one new learning strategy that may have deep influence in education (Sharples et al., 2015), aiming to combine formal and informal learning settings. For instance, one common approach that informal learning stems from is work-related tasks (Siemens, 2005) and active learning (Bonwell & Eison, 1991). This last consists in educational activities that engage physically students in the learning process, such as learning by doing things and thinking about the things they are doing (Bonwell & Eison, 1991). The gamification, for instance, is one mean to design such active educational activities. Therefore, this study aims to apply informal learning strategies in a more formal learning setting with in and out of the school activities. In this sense, the theoretical framework of this project follows the "*3T sandwich*" model (Parsons, 2015) with three layers to help the elaboration of the educational tool: (1) the *Theories* that are used to develop and inform the educational tasks; (2) the *Technology* that supports learning and interaction; and (3) the *Territories* of use with the targeted users and the stakeholders including their views and experiences.

Regarding the *Theories*, several strategies have been set to develop Virtual Museum (VM) applications that aim at either: (1) delivering information to the visitors (Kuflik et al., 2011), (2) enriching the experience by focusing on the interaction between users and exhibits (Chen & Huang, 2012; Hsieh et al., 2014; Pescarin et al., 2013; Schieck & Moutinho, 2012; Şen, Díaz & Horttana, 2012) or (3) teaching specific content around a pedagogical task (Coenen, Mostmans & Naessens, 2013; Petridis et al., 2013). The objective of "Oteiza para tod@s" is to disseminate and to explain Jorge Oteiza's concepts. Consequently, the future output belongs to this last category.
The pedagogical tasks, in an informal learning setting, are usually integrated in game-based learning environments. Some evidence suggests learning efficiency (Clark, Tanner-Smith & Killingsworth, 2016) due to the implicit use of cognitive skills such as memory or construction of knowledge (Sylaiou et al., 2009). These educational games, also known as serious games, adapt specific features of entertaining video games such as storyline or clear and short goals (Kapp, 2012), which make the experience enjoyable (Salen & Zimmerman, 2004).

There are two types of educational games, which have different aims: the mini-games and the complex-type ones. The complexity and richness of their corresponding features will influence the expected experience. For instance, complex games are usually long and combine various game mechanisms such as storyline, levels of difficulty, rewards or trophies to unblock. These latter are interesting for a deep and long-term learning process (Prensky, 2005). On the other hand, mini-games are usually short and do not require elaborated or evolutionary rules (De Jans et al., 2012; Prensky, 2005). The choice between these two types of games would depend mostly on the targeted audience, the place and the time allowed (Rivera-Gutierrez et al., 2014; Pescarin et al., 2013). For instance, visitors' museums would sometimes prefer being engaged in the "experience" of learning rather than learning content by itself (Packer, 2006). Therefore, we decided to utilise pedagogic features of gamification that are known to support children's learning such as short goals or scoring (Kapp, 2012). Gamification refers to "the use of game design elements in non-game contexts" (Deterding et al., 2011, p.9). A recent review about the increase of serious games in the field shows that about 29% of these aimed to an artistic market (Paliokas & Sylaiou, 2016). Amongst these studies, some educational games focused on engaging the visitors to interact with the museum artefacts either through quiz games (Belloti et al., 2012; Lien, 2015) or treasure hunting games (Rehm & Jensen, 2015; Yiannoutsou et al., 2014). The other approach found in the literature is to use storylines via adventure games to teach either art history with the different genres, eras and techniques (Froschauer et al., 2010) or the use of antique objects (Jenner, Moura, & Araujo, 2009). The objective of the educational games of our study differs slightly since these aim to explain artistic concepts through the manipulation of specific virtual representation of the artist's sculptures.

About the *Technology*, the current paradigms in Human-Computer Interaction (HCI) look for new means that propose engaging and intuitive interfaces via motion-based touchless interactions. These are also known as Natural User Interfaces (NUIs). One of the most common device that implements NUI is the Kinect, which is a device developed by Microsoft that detects 3D positioning and orientation of users' skeleton. The Kinect is affordable, compact and easy to use. Since the release of the Kinect in 2011, research in HCI has actively looked for the use of body gestures to interact with virtual museum content. For instance, Rivera-Gutierrez et al. (2014) exposed in a museum of science a physical exhibit where visitors were able to learn about public health via mini educational games. However, the interaction with the system was not motion based but via pushing buttons. The Microsoft Kinect was used to detect the players. Yoshida et al. (2015) proposed a pedagogical mini game designed for children (10-12 years old) to support learning about paleontological era. The project is in its early stage and although the preliminary study showed positive insights of enhancing the interests of the learners, no evidence was shown that it was due to the interaction techniques. Mora-Guiard and Pares (2014) taught the concept of nanoscale to children (11-13 years old) via an exhibit that "miniaturises" the body over a huge surface of 10x4.5m. They showed that full-body experiences provided a better sense of scales to children. This, particularly shows that such a technology can be adopted by children from secondary school. Nevertheless, the system was set in a museum with a large open space, which is a very different environment from a classroom. Finally, targeting at a younger public (4-7 years old), Paul, Goh and Yap (2015) focused on promoting creativity and collaboration. The exhibition consisted on matching alphabet letters displayed on the screen with the projection of the body. The users' participation and involvement revealed an interesting potential, although no formal evaluation was led. Again, this shows good insights that such a technology can also be adopted by children from primary school.

Concerning the *Territories*, the requisite of this project was to target students at school. The approach of this project is multidisciplinary (Art, Education and Technology) and thus, it was important to involve stakeholders in the design process of the future output. In this informal learning context, previous research has shown that the selection of the stakeholders and the type of collaboration depend mostly on the specific objectives of the project. For instance, when museums wanted to create new physical exhibits (Axelsen, Mygind & Bentsen, 2015; Dindler et al., 2010) or digital ones (Culén et al., 2013; Roussou & Ave, 2007), the research projects tended to engage typically developing children in Participatory Design (PD). These PD sessions typically consisted of an introduction to the corresponding museum field, followed by physical activities to elaborate ideas such as handicrafts (Culén et al., 2013; Taxén, 2004) or Lego plastic building blocks (Axelsen et al., 2015). On the other hand, when museums wanted to transfer knowledge (Dubois et al., 2011; Şen et al., 2012) or enrich the interaction between users and exhibits (Ciolfi et al., 2016; Coenen et al., 2013; Wishart & Triggs, 2010), the involvement of curators and ergonomists in User-Centred or Co-Design showed good results. Therefore, since the objective of this project was to convey and explain Jorge Oteiza's artistic concepts at schools, we drew upon these good practices by engaging the head of the didactics section of the museum in a Co-design approach with several brainstorming sessions.

Research hypotheses

This paper presents a multidisciplinary project that aims to transfer artistic knowledge to children at school, through edutainment. To reach such an objective, we were interested in (1) the design process by taking into account the views and experiences of stakeholders from different background, (2) the usability at schools of advanced technological devices that promote motion-based interfaces and (3) the use of gamification in the learning process.

Overall, this project contributes to the field by discussing the impact of advanced technology and edutainment on learning and engagement. Additionally, the study was set in an authentic learning context. Indeed, the digital content was designed and developed over real sculptures and concepts of the artist and it was integrated during field trips to the museum, which was organised by the schools.

Thus, this project was built over the following hypotheses:
H1: Educational mini-games help students understand and learn artistic concepts.
H2: NUIs, and particularly motion-based interfaces, help students understand and learn artistic concepts.
H3: Educational mini-games are engaging.
H4: NUIs, and particularly motion-based interfaces, are engaging.

The following section describes the design process of the educational outcome. The framework is composed of four activities related to three sculptures / concepts of the artist. The digital tool was evaluated at three levels of education: primary school, secondary school and educational practice at University. Finally, the results are detailed and discussed.

Virtual museum application: Oteiza para tod@s

Design process

The Oteiza's museum especially gives importance to the dissemination of J. Oteiza's work to children. Consequently, the museum created a didactics section which is in charge of developing activities and relationship with schools. This project "Oteiza para tod@s" aimed to disseminate J. Oteiza's work by combining Art, Education and Technology. Thus, to carry out such a multidisciplinary project several sessions were designed with stakeholders from different background: two researchers in Computer Science, one researcher in Art and Education, and the head of the didactics section of the Oteiza's museum.

Session 1: Foundation

First, the researchers visited the museum and were guided by the head of the didactics section. The tour was directed according to the different periods of the artist's life. Thus, the most representative sculptures of each artistic movement were thoroughly explained with their corresponding artistic style as well as the messages that

J. Oteiza wanted to transmit. The visit lasted approximately two hours. At the end of the session, each stakeholder was asked to list a number of sculptures that had aroused their interests.

Session 2: Selection of the content

Therefore, the objective of the second session was to select which sculptures and concepts would be digitalised. The session took place in the museum where the stakeholders shared their corresponding list with the reasons why they chose these sculptures. The head of the didactics section confirmed and corrected the researchers' interpretation of the artist's concepts. The selection of the final sculptures was decided by the common stakeholders' interests, the technical feasibility estimated by the researchers' point of view, and the potential added-value that VR can provide regarding the classic activities organised by the didactics section. Thus, the final selection was reduced to three sculptures.

Session 3: Idea generation

Finally, the last design session aimed to define the activities related to the corresponding concept of the sculptures. The stakeholders had previously decided to design mini-games because, contrarily to complex-games, a mini-game usually focuses on a single concept by using basic and easy-to-use game mechanisms (De Jans et al., 2017). Furthermore, mini-games facilitate the feeling of "challenge" with increasing levels of difficulties and the possibility of outperforming personal or other players' score (Illanas et al., 2008). In that sense, Amr (2012) argues that challenges positively influence learning because the players feel a sense of achievement, which help them keep engaged. Serious games can be classified according to the Gameplay/Purpose/Scope model (Djaouti, Alvarez & Jessel, 2011). The scope refers to the market-based classification, which is in this study "Culture and Art." The purpose is three-fold: broadcasting a message, training or exchanging data. The aim of this project is to transmit an educative message through the mini-games. Finally, the gameplay refers to the main features of the games. In other words, how the users interact with the game to fulfil the corresponding purpose. These gameplays can be grouped in two categories: Game-based (Destroy, Match, Avoid, Block) and Play-based (Have luck, Write, Select, Move, Manage, Shoot, Create) (Djaouti et al., 2011).

Therefore, in order to optimise the session, the lead researcher (first author) proposed a scenario for each of the activities as a starting point. Each scenario defined a specific task to complete and elements of interaction. Then, for each activity, the ideas were discussed and adapted until all the stakeholders agreed on the main plot and features. At the end, all the stakeholders agreed on designing the mini-games with the game-based "Match" mechanism, and the play-based "Select, Move and Create" interactions. These mechanisms fit the main concepts of the artist, which are mostly based on the way the sculptures were created and their relationship with the environment regarding the point of view.

The mini games

The software was developed using C#, the Microsoft Kinect SDK and GoblinXNA as rendering engine. It was decided that the games would not diffuse any sound because it can be disruptive in both school and museum environment (Economou, 1999).

Negative aesthetic via subtraction

The first activity was inspired of a permanent exhibit which is exposed in Pamplona, Spain. The sculpture had been built by removing spherical matters which resulted in a two-column shape (see Figure 1). The concept behind this sculpture, however, is the negative aesthetic. Therefore, it is important to focus the attention not only on the sculpture but also on the invisible matter generated by this latter. In order to explain this first concept, the mini game moves automatically the users' point of view around a virtual reproduction of the sculpture (not strictly identical to the original one). Then, the objective is to find out of four possibilities the empty space that matches the invisible matter (see Figure 1). The player must analyse the scene from the specific point of view, and decide the option with the "Select" feature. To select an option, the users should point at the screen and move the projection of the hand towards the corresponding icon at the top of the screen. If the player fails, a cross is drawn on the wrong selection as feedback and the player can still select another option, however, the final score will decrease. Once the solution has been found, the invisible matter is highlighted and turns into spherical shapes to explain the real reasoning of the artist. The gameplay feature is limited to selection to let the player all necessary time to observe and understand the scene with a reduced cognitive load.

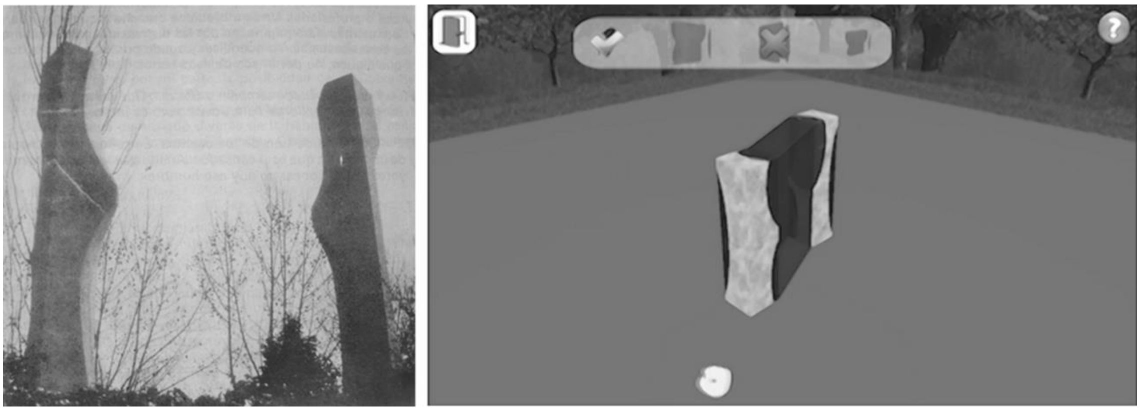

Figure 1. On the left, picture of the real sculpture. On the right, screenshot of the corresponding activity

Negative aesthetic via addition

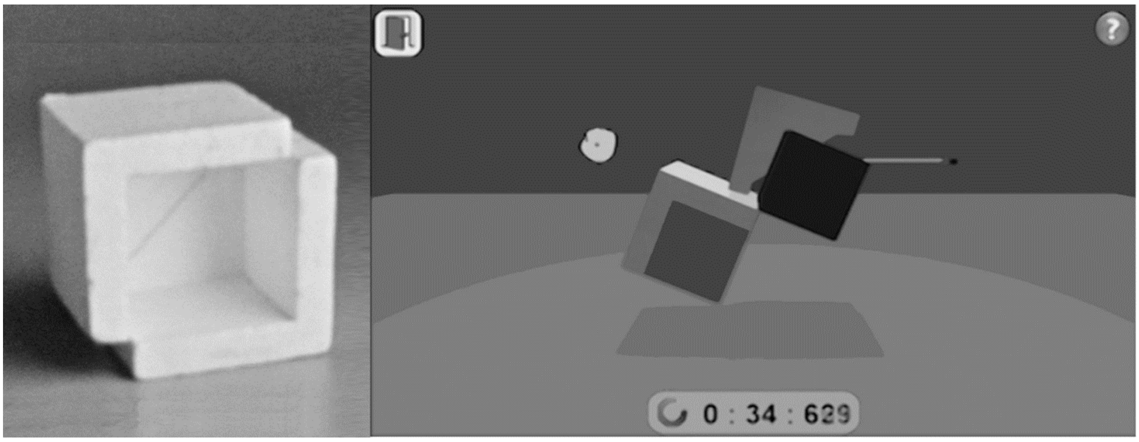

Figure 2. On the left, picture of the real sculpture. On the right, screenshot of the corresponding activity

Activation of space and time

The second activity was based on a sculpture created by addition of matter (see Figure 2). The concept behind this work is also negative aesthetic, although this time the invisible matter is not spherical but cubic. Since this sculpture was built by addition, the mini game offers similar mechanisms. The position and orientation of half of the piece is set in the scene with its invisible matter highlighted in green (light grey in Figure 2). The user manipulates the second part of the sculpture by using the Crank Handle technique (Bossavit et al., 2014). This is a one-hand manipulation technique were the movement of the hand is transferred to the virtual object and its orientation is set with a circular movement of the hand around one of the three primary axis as if the user were turning a crank handle. The corresponding invisible matter of the second piece is highlighted in blue (dark grey in Figure 2) to its final position within the final sculpture (see Figure 2). Thus, the user has to position and orientate this second half of the sculpture in order to encapsulate its corresponding invisible matter (highlighted in blue) while being in direct contact with the static bit. This final position will shape one and unique sculpture. The feature of the game is, then, limited to "Move," in order to let the user reproduce the construction of a sculpture by taking into account the environment. In that sense, collisions are calculated so that the two pieces cannot overlap. Furthermore, an extra magnet feature is activated when the two pieces are closed to the solution, and thus, the manipulated piece is automatically placed to match the fixed one. Several sculptures are designed so that users will not perform the same one twice in a row. The challenge is increased by adding time to the task completion. Indeed, the task should be completed within a time range limit (40 seconds) otherwise the solution would be animated once the time is over.

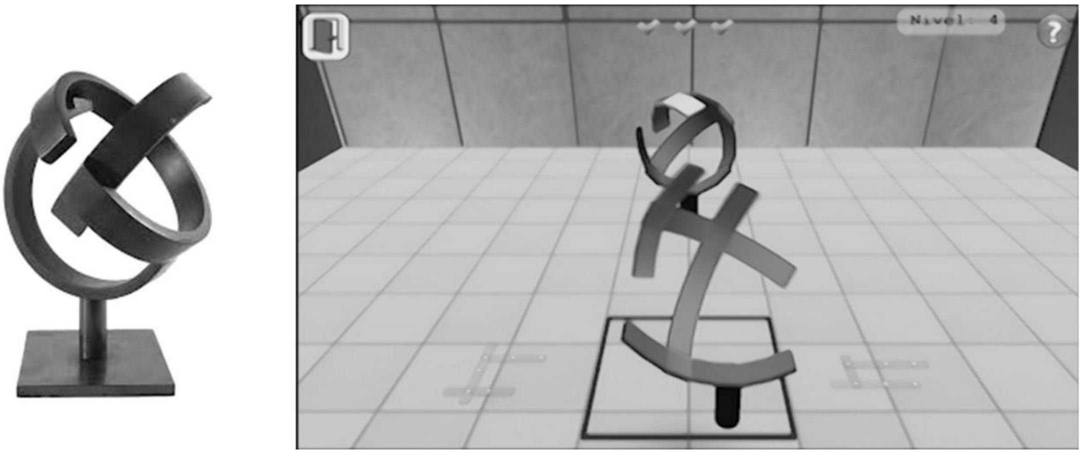

Figure 3. On the left, picture of the real sculpture. On the right, screenshot of the corresponding activity

The third activity was based on a sculpture for which J. Oteiza had found inspiration in Pieter Mondrian's work. J. Oteiza represented the activation of the space by curving Mondrian's parallel and perpendicular lines which resulted in an opened spherical shape (see Figure 3). It is important to state that the sphere is only defined by its negative aesthetic. Furthermore, the concept behind this work remains somehow open to interpretation because, and in accordance with the didactics section of the Oteiza's museum, the strips would not only represent the surface of the negative sphere. Indeed, each strip would also stand for a "negative" sphere at one specific time. As a result, the mini game was designed with two stages. During the first phase, the user is presented several "flat" patterns and has to find which one fits the model (see Figure 3). At this stage, the player is offered the "Select" feature to choose the correct model. The user can manipulate a virtual ray, which is the extension of the arm, by pointing at the screen. Once the virtual ray intersects a starting point of a strip, which is represented by a small sphere, the user can activate the concept of space by closing the hand. Thus, an animation, which shows how the "flat" pattern converts into the final sculpture, would be launched. In case of wrong answer, the generated sphere comes back to its original flat shape, and the player loses a life and is given a new opportunity. Several levels are designed to increase the difficulty. The first level has one "flat" pattern with several starting points. The second level has three patterns with only one starting point each. Afterwards, the level has three patterns with several starting points. Once the player loses all the lives or reaches the last level, the strips of the generated sphere are animated around the negative sphere. Each strip moves independently at different speeds. Then, the user is offered the "Move" feature to reconstruct the original sculpture by rotating the strips one by one using the Crank Handle technique (Bossavit et al., 2014). Therefore, this activity proposes both the "Select" feature to have time to observe the scene and the "Move" feature to feel the concept behind the construction of the sculpture. The challenge increases with levels and is enhanced with a limited numbers of lives.

Pilot study

Once the three activities were implemented, a session was set in the Oteiza's museum with the vice director of Oteiza's museum and three professors in art history (two from the University of Barcelona in Spain and one from the Public University of Navarre in Spain). The session was organized in three stages. First, all the stakeholders visited the museum (approximatively one hour). Then, the researchers explained the different activities and how to interact. The stakeholders were given the possibility to interact as well (about one hour). At the end, the participants provided feedback in order to improve the representation of the activities (reported in the "Findings and Discussion" section).

Furthermore, they found that activities all lacked the presence of creativity. This was also suggested by Kuo et al. (2009) who called for adding artistic teaching materials into E-learning programs. Thus, they suggested that users should be able to create their own sculpture based on the concept outlined by the software. Consequently, we added the "Create" feature within a new activity that allows users to add and edit pieces by changing their size (length, width and thickness), their curvature and their position / orientation. Users can manipulate the pieces separately or together. They are also offered the possibility to observe the invisible matter that the sculpture creates (see Figure 4). The 3D manipulation is done via the Crank Handle technique (Bossavit et al., 2014) and the parameters that change the shape of the piece are controlled by sliders. We proposed two techniques to manipulate the sliders: (1) via a constant step by touching the shoulders with the hand; (2) via an interpolated value. For this second technique, an unfolded user's arm stands for the slider while the other hand represents the tick between the hand and the shoulder (Shoemaker et al., 2010).

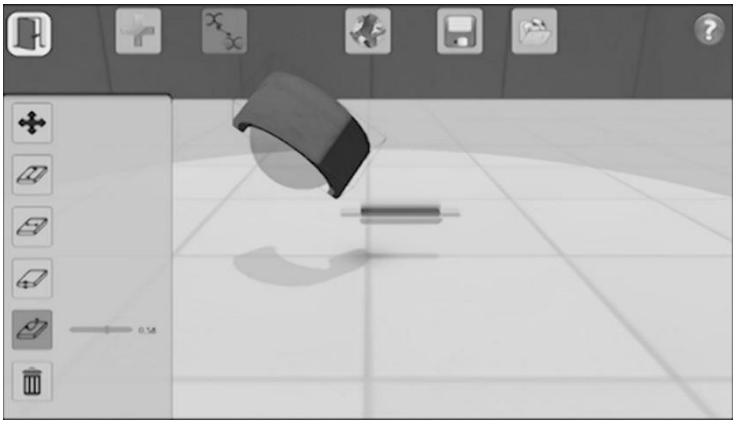

Figure 4. Screenshot of the last activity which focuses on the creation of a sculpture that is based on the concepts learnt from the other three activities

Evaluation at schools

This evaluation study seeks for the impact of technological input on the illustration of artistic concepts at schools. However, the design and development of this educational tool does not intend to replace the visit of the museum but to enhance it. Consequently, comparing the impact of this tool as an alternative to the visit at the museum is beyond the scope of this evaluation.

Participants

Schools usually organise field trips to museums from primary to University. Therefore, participants from different ages and educational stages had been recruited for this study. The first group was composed of 57 primary pupils from a state school of Pamplona, Spain. Participants' mean age was 7.14 (*SD* = 0.43) which included 21 male and 36 female. 28 participants played with the software (active) and 29 just watched (passive). The second group was composed of 60 secondary pupils from another state school of Pamplona, Spain. Participants' age was 14.55 (*SD* = 0.58) which included 24 male and 36 female. 19 participants played with the software (active) and 41 just watched (passive). The last group was composed of 21 students in educational practice at the Public University of Navarre, Spain. Participants' mean age was 22.1 (*SD* = 2.67) which included 2 male and 19 female. 13 participants played with the software (active) and 8 just watched (passive).

Procedure

Each group followed the same procedure. None of the educational institutions teaches content about J. Oteiza in their programme, thus, according to the teachers, the class before the visit to the museum was an introductory session about the artist.

Afterwards, the pupils and students visited the Oteiza's museum during approximatively one hour. The visit was guided by the head of the didactics section of the museum. The tour started with a presentation of J. Oteiza who is a reference as artist and intellectual of the twentieth century. Then, the visit continued on the permanent exhibits with the most representative sculptures. Not only does Oteiza's work open to specific concepts such as figurative/abstract art, movement/space, or visible/non-visible matter, but it also refers to social art and sculpture-architecture relationship.

Later, within a range of one to four weeks after the visit of the museum (according to the availability of the schools), the researchers were contacted to evaluate the use of the software with the students during one of the mainstream teaching session at the school. Thus, we setup two installations in the same room so that participants had more opportunities to play. The game was projected onto a wall with the Kinect under it and the interacting student was placed at about 2 meters from the screen (see Figure 5). The session lasted 50 minutes during which the students could voluntarily test one out of the four activities for about 40 minutes in total. The researchers were there to help the users interact if required. For the last 10 minutes, the participants were asked to fill questionnaires (see further details below).

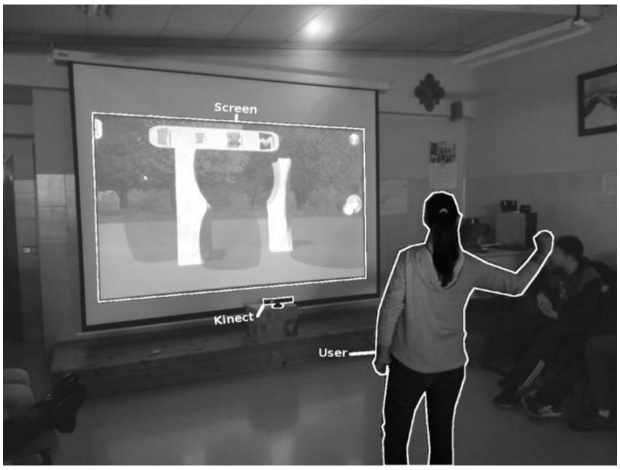

Figure 5. Overview of the apparatus with all the elements outlined (screen, Kinect and user)

Results

This study is based on the hypotheses that the targeted users' experience, through mini games and motion-based interfaces, help understand and learn artistic concepts (H1 and H2), and are engaging (H3 and H4). Therefore, we used two different questionnaires to measure these statements, and for all the results we looked different independent variables, i.e., Gender (whether participants were (1) Male or (2) Female); Device (whether participants interacted with the software: (1) Active or (2) Passive interaction); and Education (whether participants are from (1) Primary, (2) Secondary or (3) Educational Practice).

Two-tailed independent samples *t*-tests were performed on the participants' scores for the two independent variables Gender and Device. And one-way ANOVAs were performed for the comparison between the three groups of participants regarding Education. Pairwise comparisons adjusted by a Bonferroni correction were applied when significant differences appeared.

Learning experience

The participants' learning experience was surveyed with a multiple choice questionnaire composed of ten questions with four possible answers each (see Table 1). The first fifth questions (part I) were related to the author himself and the second half (part II) quizzed about the Oteiza's concepts treated by the software. The questions were elaborated by the head of the didactics section of the museum and it was given out at the pre-visit session and after testing the mini-games. The "post-test" was the same as the "pre-test" although the answers were inverted.

Table 1. Questionnaire that was used to evaluate the learning experience (answers are highlighted in italic)

Category	Questions	Answers
Learning Oteiza	1. Where is Jorge Oteiza born?	San Sebastián / Pamplona / *Orio* / Bilbao
	2. In the field of Art, Oteiza was well-known for?	Moviemaker / *Sculptor* / Painter / Architect
	3. In 1935 the artist had left Spain for another country in which he had been working as teacher and artist until 1948. Where was it?	France / Germany / *South America* / Italy
	4. Which is the city that owns the most work of Oteiza within the streets?	*Pamplona* / San Sebastián / Biarritz / Madrid
	5. The Oteiza's museum was designed by an architect from Navarre. Who was he?	*J. Sáenz de Oíza* / F. Mangado / R. Moneo / V. Eusa
Learning Concepts	6. Which geometric shapes does Oteiza base his work on?	*Cylinder, sphere & cube* / Circle, square & trapeze / Sphere, cone & cube / Cylinder & sphere
	7. Which context is the most important when one is studying Oteiza?	Movement / Shape / *Empty space* / Color
	8. Which one is the most related to space	The sculpture fills a space /

according to Oteiza?	No direct relationship between sculpture and space / The empty space means nothing to the sculpture / *The empty space can become a sculpture*
9. How many dimensions can be observed in a sculpture?	Two / one or two / *three* / two or three
10. Does the color mean something to the sculpture?	*Yes, since it changes its aspect* / No, it is only important in painting / No, it is only important in painting and drawing / Only if the sculpture is figurative

In order to analyse the learning gains, dependent variables were defined:

- Learning = ((post-test – pre-test) / 10) * 100
- Learning_Oteiza = ((post-test_partI – pre-test_partI) / 5) * 100
- Learning_Concepts = ((post-test_partII – pre-test_partII) / 5) * 100

The results of the statistical analysis over this questionnaire are summarised in the Table 2. The dependent variable "Questionnaire" represents the score over 10 points. Each correct answer was marked one point. The three abovementioned dependent variables "Learning," "Learning_Oteiza" and "Learning_Concepts" represent the percentage of increased knowledge between the "pre-test" and the "post-test." The independent variables were not reported when there were no significant differences.

Table 2. Statistic results of the learning experience (significant differences are marked with an asterisk)

Group	Dependent variable	Independent variable	Mean	*SD*	Results	*Sig.*
Primary	Questionnaire	Pre-test	2.57 (/10)	1.55	$t(56) = 8.8$	$^{***}p < .001$
		Post-test	4.49 (/10)	1.96		
	Learning	Male	16.6 (%)	17.12	$t(55) = -0.862$	$p > .05$
		Female	20.5 (%)	16.02		
		Active	14.6 (%)	13.7	$t(55) = 2.08$	$^{*}p < .05$
		Passive	23.4 (%)	17.7		
	Learning_Oteiza	Active	17.14 (%)	22.25	$t(55) = 0.76$	$p > .05$
		Passive	22.06 (%)	26.37		
	Learning_Concepts	Active	12.14 (%)	19.88	$t(55) = 2.29$	$^{*}p < .05$
		Passive	24.82 (%)	21.81		
Secondary	Questionnaire	Pre-test	4.88 (/10)	1.51	$t(59) = -9.71$	$^{***}p < .001$
		Post-test	6.98 (/10)	1.38		
	Learning	Male	14.58 (%)	16.14	$t(58) = 2.53$	$^{*}p < .05$
		Female	25.27 (%)	15.94		
		Active	18.42 (%)	18.63	$t(58) = 0.81$	$p > .05$
		Passive	22.19 (%)	15.89		
	Learning_Oteiza	Male	19.16 (%)	16.12	$t(58) = 1.35$	$p > .05$
		Female	25.55 (%)	18.88		
	Learning_Concepts	Male	10 (%)	26.34	$t(58) = 2.22$	$^{*}p < .05$
		Female	25 (%)	24.31		
Educational Practice	Questionnaire	Pre-test	7.00 (/10)	1.51	$t(20) = 3.11$	$^{*}p < .01$
		Post-test	8.19 (/10)	1.28		
	Learning	Male	10 (%)	14.14	$t(19) = -0.15$	$p > .05$
		Female	12.1 (%)	18.12		
		Active	11.53 (%)	18.63	$t(19) = -0.11$	$p > .05$
		Passive	12.5 (%)	16.69		
Inter groups	Learning_Oteiza	Primary	19.64 (%)	24.34	$F(2,135) = 0.4$	$p > .05$
		Secondary	23 (%)	17.97		
		Educational practice	20 (%)	20		
	Learning_Concepts	Primary	18.59 (%)	21.66	$F(2,135) = 3.38$	$^{*}p < .05$
		Secondary	*19 (%)	26.4		
		Educational practice	*3.8 (%)	24.99		
	Learning	Active	15.16 (%)	16.41	$t(136) = 2.27$	$^{*}p < .05$

	Passive	21.66 (%)	16.78		
	Male	15.31 (%)	16.26	$t(136) = -1.77$	$p > .05$
	Female	20.65 (%)	16.98		

Note. $^{*}p < .05$; $^{***}p < .001$.

Engagement

The participants' experience was surveyed via a 5-Likert scale questionnaire with 12 questions. Four questions were related to motivation (1-4), four about usability (5-8) and four about utility (9-12). The questionnaire was given out at the end of the session after testing the mini-games (see Table 3).

Table 3. Questionnaire that was used to evaluate engagement and motivation

Category	*Question*	
Motivation	1.	I like going to museums
	2.	When I am in a museum I usually watch the exhibits
	3.	When I am in a museum I like spending time with the interactive exhibits
	4.	I enjoyed the experience and learnt about Oteiza's work
Usability	5.	I found it easy using the application
	6.	I found it difficult understanding what I had to do
	7.	I could use this application without the help of an adult
	8.	I found it difficult completing the activities
Utility	9.	I think the application helped me understand better J. Oteiza's work
	10.	I think the visit to the museum is enough to understand J. Oteiza's work
	11.	I would like such an application in my school
	12.	I would go more often to museums if such kind of applications would be set up

The analysis of internal consistency reliability of the questionnaire revealed a Cronbach's alpha coefficient at 0.695. The Cronbach's alpha coefficient ranges between 0 and 1 and an acceptable minimal reliability value is 0.7 (Nunnaly, 1978). The results of the statistical analysis on the three dependent variables: Motivation, Usability and Utility are summarised in the Table 4. The score displayed in the "Mean" column represents the sum of the answers of the four questions corresponding to the dependent variable. The mark is over 20.

Table 4. Statistic results of the questionnaire about engagement (significant differences are marked with an asterisk)

Dependent variable	Independent variable	Mean	*SD*	Result	*Sig.*
Motivation	Male	13.91	3.18	$t(134) = -3.66$	$^{*}p < .05$
	Female	15.77	2.6		
	Active	15.81	2.68	$t(134) = 2.4$	$^{*}p < .05$
	Passive	14.61	3.03		
	Primary	*16.5	2.98	$F(2,133) = 15.42$	$^{***}p < .001$
	Secondary	*13.76	2.52		
	Educational practice	15.31	2.05		
Usability	Male	12.04	3	$t(134) = -0.63$	$p > .05$
	Female	12.38	2.97		
	Active	12.57	3.28	$t(134) = 1.06$	$p > .05$
	Passive	12.02	2.71		
	Primary	12.12	3.31	$F(2,133) = 0.87$	$p > .05$
	Secondary	12.6	2.68		
	Educational practice	11.63	2.79		
Utility	Male	13.55	2.95	$t(134) = -2.28$	$^{*}p < .05$
	Female	14.7	2.72		
	Active	14.88	2.1	$t(134) = 2.07$	$^{*}p < .05$
	Passive	13.87	3.25		
	Primary	*14.98	2.39	$F(2,133) = 3.31$	$^{*}p < .05$
	Secondary	*13.65	3.19		
	Educational practice	14.36	2.56		

Findings and discussion

This project aims at disseminating the artistic concepts of J. Oteiza to children at school. Thus, the adopted learning strategies mixed formal and informal learning by using interactive gaming activities to promote individual learning. In this sense, we hypothesised that educational mini-games and motion-based interfaces would help participants understand and learn abstract artistic concepts and being engaging.

Research hypotheses

In terms of the impact of the educational mini-games in the learning process, the scores of the questionnaires show that all the groups increased their knowledge significantly (see Table 2). The overall learning experience aimed to provide information about the artist (mostly from the museum visit) as well as his artistic concepts (mostly from the mini-games). The increase of knowledge about J. Oteiza is similar to all the groups (between 19.6% and 23.0%, see Table 2). This means that the visit of the museum was efficient to everyone. On the other hand, the increase of knowledge about the artist's concepts varied depending on the educational group. The pupils from secondary school learnt the most (increase of 19%, see Table 2), followed by the ones from primary school (increase of 18.5%, see Table 2). This puts forward the fact that children from 7-8 years are, indeed, able to learn complex concepts as suggested by Antoniou et al. (2013). However, the students from educational practice showed a very small progression (increase of 3.8%, see Table 2). This is probably due to the fact that concepts such as invisible matter and spatiotemporal dimensions are already assimilated by adults.

Concerning the impact of the technology, we compared the scores obtained by the users who interacted with the software and the one who only saw the others interacting. People's behaviour and expectation regarding digital exhibits might vary from the environment. For instance, in museums, visitors tend to understand and learn through active participation (Kampouropoulou et al., 2013). However, in this study, students who did not interact directly with the software learnt significantly more (increase of 21.6% against 15.1%, see Table 2). An explanation of such results might be humans' social boundaries issues. Indeed, the students interacted in front of their colleagues, which might be a very stressful experience due to the importance we give to the judgment of people that surround us (Feinstein, 2004). Thus, most of the students' attention might have focused on the way they behaved instead of the task by itself. Furthermore, the stress is higher when people are socially closer. In museums, this pressure is lowered and some people manage to negotiate these social boundaries (Schieck & Moutinho, 2012; Paul et al., 2015). Another reason that could explain why the students learnt more when they were not active is the cognitive load that was required by the interface. Indeed, all the participants did not score high usability of the system (score of 12 out of 20, see Table 4), which means that they found it relatively difficult. The activities were designed with the Crank Handle technique (Bossavit et al., 2014), which allows manipulation of six degrees of freedom (three for translation and three for rotation). Although the technique is easily understandable because it is based on a common metaphor, which is rotating a crank handle, the accuracy of the Kinect requires users to perform clear gestures. Thus, this technique does entail some training that the children did not have. Consequently, it might be judicious to provide more assistance to the users by limiting the complexity of the gestures (Pescarin et al., 2013; Yoshida et al., 2015) as well as the amount of actions (Hsieh et al., 2014; Mora-Guiard & Pares, 2014).

In terms of engagement, besides improving significantly their understanding of the abstract notions, the pupils from primary school revealed the highest rate of motivation (score of 16.5 out of 20, see Table 4) and usefulness (score of 14.9 out of 20, see Table 4). Thereafter, the primary school teacher commented that the session had motivated her and she organised a workshop where children could sculpt and collage works related to J. Oteiza's concepts (see Figure 6). Surprisingly, the teenagers, who increased the most their knowledge, revealed the least motivation (score of 13.7 out of 20, see Table 4) and just found the experience somehow useful (score of 13.6 out of 20, see Table 4). This contrast has already been observed in museums where the enjoyable experiences and the amount of cognitive learning varied regarding the group of participants (Griffin, 2004).

About the impact of the technology, the participants who interacted with the software revealed a higher motivation (score of 15.8 against 14.6 out of 20, see Table 4) and a higher score in utility (score of 14.8 against 13.8 out of 20, see Table 4). This goes in line with the literature that also revealed evidence of this type of interfaces being engaging (Hsu, 2011; Lee et al., 2012).

Theoretical framework

Nevertheless, all these results suggest some important recommendations for future practitioners and academics regarding the elaboration of the theoretical framework. This study was grounded in the "*3T sandwich*" model (Parsons, 2015) that focuses on three aspects: the *Theories* (in this project the gamification), the *Technology* (motion-based interfaces) and the *Territories* of use (students as target and multidisciplinary stakeholders as designer).

Regarding the gamification, beside the fact that mini games are engaging and help increase knowledge, another interesting outcome is the gender effect. Indeed, female participants were the most engaged, they found the experience more motivating than male participants (score of 15.7 against 13.9 out of 20, see Table 4) and more useful (score of 14.7 against 13.5 out of 20, see Table 4). This might be explained by the fact that girls tend to prefer games that require cognitive skills instead of destruction-like games (Pasek, 2008; Pelletier, 2008). Furthermore, it appears that female participants increase the most their knowledge (20.6% against 15.3%, see Table II) and especially in secondary school (25.2% against 14.5%, see Table 2). This suggests that gender issues should be taken into account when designing educational games in order to adapt the content to the main preferences of the participants (Holtzblatt & Kules, 2017; Kafai, 2008).

In terms of technology, this study shows that albeit motion-based interfaces are engaging, these kinds of devices are not well adapted in a school context. Indeed, it is limited to one or two players at the same time, which can affect social boundaries regarding the others students. Additionally, it also requires an open space without occlusion in order to avoid interferences.

Finally, concerning the design methodology, the results of the pilot study showed that the collaboration with the didactics section of the museum was indeed efficient since at the first try, all the experts agreed that the activities did explain J. Oteiza's abstract concepts. However, we do recommend an extra iteration with different experts to ensure that the key message is conveyed correctly. Indeed, the stakeholders' experience in pedagogy and art revealed important improvements for the interpretation of the abstract concepts. For instance, the stakeholders considered that the tutorials, which explained how to interact with the software, were represented the same way as the pedagogical information. Therefore, they suggested replacing the text by simple animations, which apart from being more visual would definitely separate interactions from pedagogical aspects (Antoniou et al., 2013). Another interesting aspect is that all the stakeholders agreed that it would be interesting to add new quotations of J. Oteiza within the games so that it would impregnate the user with Oteiza's personality. Finally, they felt like the objective of the game was to replace the visit of the museum. As a result, they accentuated that this digital tool should be a complement to the visits, which was also suggested by Sylaiou et al. (2009). This is an important aspect that should be taken into account because it affects the future design of the educational tools.

Figure 6. Pictures of the workshop of the pupils from primary school

Limitations and recommendations

Although, the design and development of this educational tool did not intend to replace the visit of the museum but to enhance it, the presence of a control group could improve consequently the data analysis by quantifying the different impact on the final learning progress from the visit of the museum and the use of the mini-games.

Another limitation of this study is the qualitative questionnaire (see Table 3). It was designed by the researchers and its reliability Cronbach's alpha coefficient was at 0.695 when an acceptable rate is 0.7. This means that, strictly speaking, the questionnaire may be questionable and this let the readers decide about its relevance.

Anyhow, the current study revealed some interesting limitations that can be avoided in further studies. For instance, motion-based interaction games at school deal with humans' social boundaries issues, which has a direct impact on the learning process. Therefore, it might be more judicious to either (1) design games that requires a more anonymised interactions by using more classical interfaces like mouse and keyboard, or (2) organise individual or open sessions where the students can interact when they feel more confident.

Furthermore, using motion-based interaction might require a certain cognitive load, which may hinder the learning process. Thus, we recommend providing more assistance to the users by limiting the complexity of the gestures.

Conclusions

A series of mini games that shed light on Jorge Oteiza's artistic concepts to children have been co-designed with the didactics section of a museum. In informal learning settings such as Art Museums, the educational content are strictly related to specific concepts / artefacts, which make the outcomes poorly replicable. That is why, in this study, the emphasis was also put on the design methodology based on the 3T sandwich model. The framework was evaluated by children from primary and secondary schools and students from educational practice in order to validate the design of the educational mini-games using of Natural User Interfaces. Thus, both the analysis of the users' experience towards the technology and their learning experience helped us provide some recommendation to future practitioners in order to ground the theoretical framework. For instance, about learning outcome, the participants did learn more about Jorge Oteiza as well as his artistic concepts, including children from primary school. This shows that the designed educational tool completes its objective efficiently. Regarding the targeted users, the study highlights the interesting fact that girls were, in fact, more engaged and learnt the most. This might be due to the game mechanisms which focused more on cognitive than destruction-like skills. Besides, it was observed that, contrary to visits at museums, participants who did not interact were more likely to understand and increase their knowledge. This means that an informal tool based on active learning may have another effect within a formal learning context. This might be a consequence of using Natural User Interfaces at school, where the, participants had to interact alone in front of all their friends, which obliged them to negotiate their social boundaries beyond shyness and stress. This side effect might be reduced by limiting the interaction to simple gestures so that participants can focus more on the educational content.

Overall, we argue that applying informal educational learning tools within a formal learning context enhances Museum experiences and link them to classrooms, which promotes crossover learning. However, this is a short-term study of an overall project that deals with advanced technologies, on the one hand, and learning strategies, on the other hand. Therefore, it would also be interesting to complement this study with two additional evaluations. For instance, one study should focus on the real impact of advanced technologies at school by using this same framework but with different technology. The other study should specifically focus on the learning strategies comparing formal educational tools with this game-based learning tool using a control group.

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References

Álvarez Martínez, M. S. (2003). *Jorge Oteiza: Pasión y razón* [Jorge Oteiza: Passion and reason]. San Sebastián, Spain: Nerea Editorial.

Amr, K. (2012). *Learning through games: Essential features of an educational game* (Unpublished doctoral dissertation). Syracuse University Syracuse, NY. Retrieved from https://surface.syr.edu/idde_etd/56

Antoniou, A., Lepouras, G., Bampatzia, S., & Almpanoudi, H. (2013). An Approach for serious game development for cultural heritage : Case study for an archaeological site and museum. *Journal on Computing and Cultural Heritage, 6*(4), 1–19. doi:10.1145/2532630.2532633

Axelsen, L. V., Mygind, L., & Bentsen, P. (2015). Designing with children: A Participatory design framework for developing interactive exhibitions. *Journal of Inclusive Museum, 7*(1), 1-16. doi:10.18848/1835-2014/CGP/v07i01/44473

Bellotti, F., Berta, R., de Gloria, A., D'Ursi, A., & Fiore, V. (2012). A Serious game model for cultural heritage. *ACM Journal on Computing and Cultural Heritage*, *5*(4), 1-27. doi:10.1145/2399180.2399185

Bonwell C., & Eison J. (1991). *Active learning: Creating excitement in the classroom.* Washington, DC: George Washington University.

Bossavit, B., Marzo, A., Ardaiz, O., Diaz de Cerio, L., & Pina, A. (2014). Design choices and their implications for 3D mid-air manipulation techniques. *Journal Presence: Teleoperators and Virtual Environments*, *23*(4), 377-392. doi:10.1162/PRES_a_00207

Bowen, J. P., & Filippini-Fantoni, S. (2004). Personalization and the web from a museum perspective. In *Proceedings of Museums and the Web* (pp. 63–78). Washington, DC: Archives & Museum Informatics.

Chen, C.-C., & Huang, T.-C. (2012). Learning in a u-Museum: Developing a context-aware ubiquitous learning environment. *Journal of Computers & Education*, *59*(3), 873–883. doi:10.1016/j.compedu.2012.04.003

Ciolfi, L., Avram, G., Maye, L., Dulake, N., Marshall, M. T., van Dijk, D., & McDermott, F. (2016). Articulating co-design in museums: Reflections on two participatory processes. In *Proceedings of Computer-Supported Cooperative Work and Social Computing* (pp. 13–25). doi:10.1145/2818048.2819967

Clark, D., Tanner-Smith, E., & Killingsworth, S. (2016). Digital games, design and learning: A Systematic review and meta-analysis. *Review of Educational Research*, 86(1), 79-122. doi:10.3102/0034654315582065

Coenen, T., Mostmans, L., & Naessens, K. (2013). MuseUs: Case study of a pervasive cultural heritage serious game. *Journal on Computing and Cultural Heritage*, *6*(2), 1–19. doi:10.1145/2460376.2460379

Culén, A. L., Bratteteig, T., Pandey, S., & Srivastava, S. (2013). The Child-To-Child (C2C) method : Participatory design for, with and by children in a children's museum. *IADIS International Journal on WWW/Internet*, *11*(2), 92–113.

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: defining gamification. In *Proceedings of International Academic MindTrek Conference: Envisioning Future Media Environments* (pp. 9-15). doi:10.1145/2181037.2181040

De Jans, S., Van Geit, K., Cauberghe, V., Hudders, L., & De Veirman, M. (2017). Using games to raise awareness: How to co-design serious mini-games? *Journal of Computers and Education*, *110*, 77–87. doi:10.1016/j.compedu.2017.03.009

Dindler, C., Iversen, O. S., Smith, R., & Veerasawmy, R. (2010). Participatory design at the museum - Inquiring into children's everyday engagement in cultural heritage. In *Proceedings of Australasian Computer-Human Interaction Conference* (pp. 72–79). doi:10.1145/1952222.195223

Djaouti D., Alvarez J., & Jessel, J. P. (2011). Classifying serious games: G/P/S model. In P. Felicia (Ed.), *Handbook of Research on Improving Learning and Motivation through Educational Games: Multidisciplinary Approaches* (pp. 118-136). Waterford Institute of Technology, Ireland: IGI Global. doi:10.4018/978-1-60960-495-0.ch006

Dubois, E., Bortolaso, C., Bach, C., Duranthon, F., & Blanquer-Maumont, A. (2011). Design and evaluation of mixed interactive museographic exhibits. *International Journal of Arts and Technology*, *4*(4), 408-441.

Echeverria-Plazaola, J. (2012). Jorge Oteiza and the "negative aesthetics": Towards an understanding of the sacred in abstract art. *International Journal of the Humanities*, *9*(11), 153–166.

Economou, M. (1999). The Evaluation of museum multimedia applications : Lessons from research. *Museum Management and Curatorship*, *17*(2), 173–187. doi:10.1016/S0260-4779(98)00043-0

Feinstein S. G. (2004). *Secrets of the teenage brain: Research-based strategies for reaching and teaching today's adolescents*. Thousand Oaks, CA: Corwin Press, A SAGE Publications Company.

Froschauer J., Arends M., Goldfarb D., & Merki D. (2012). A Serious heritage game for art history: Design and evaluation of ThIATRO. In *Proceedings of Virtual Systems and Multimedia* (pp. 283-290). doi:10.1109/VSMM.2012.6365936

Griffin, J. (2004). Research on students and museums: Looking more closely at the students in school groups. *Science Education*, *88*, S59–S70.

Holtzblatt, K., & Kules, B. (2017). Using games for good to address diversity in high tech. In *Proceedings of Conference on Human Factors in Computing Systems* (pp. 1338-1341). doi:10.1145/3027063.3049279

Hsieh, C., Liao, W., Yu, M., & Hung, Y. (2014). Interacting with the past : Creating a time perception journey experience using Kinect-based breath detection and deterioration and recovery simulation technologies. *Journal on Computing and Cultural Heritage*, *7*(1), 1–15. doi:10.1145/2535937

Hsu H. M. J. (2011). The Potential of Kinect in education. *International Journal of Information and Education Technology*, *1*(5), 365-370. doi:10.7763/IJIET.2011.V1.59

International Council of Museums (ICOM). (2007). *Museum definition-ICOM*. Retrieved from https://icom.museum/en/activities/standards-guidelines/museum-definition/

Illanas, A. I., Gallego, F., Satorre, R., & Llorens, F. (2008, March). *Conceptual mini-games for learning*. Paper presented at the 2nd International Technology, Education and Development Conference (INTED2008), Valencia, Spain.

Jenner W., Moura L., & de Araujo M. (2009). Hanse 1380 - A Learning game for the German maritime museum. In *Lecture Notes in Computer Science* (Vol. 5794, pp. 794-799). doi:10.1007/978-3-642-04636-0_86

Lee W. J., Huang C. W., Wu C. J., Huang S. T., & Chen G. D. (2012). The Effects of using embodied interactions to improve learning performance. In *Proceedings of International Conference on Advanced Learning Technologies* (pp. 557-559). doi:10.1109/ICALT.2012.104

Kafai, Y. B. (2008). Considering gender in digital games: Implications for serious game designs in the learning sciences. In *Proceedings of the Computer-Supported Collaborative Learning Conference (CSCL)* (pp. 422-429). Utrecht, The Netherlands: International Society of the Learning Sciences.

Kampouropoulou, M., Fokiali, P., Efstathiou, I., & Stefos, E. (2013). The Virtual museum in educational practice. *Review of European Studies*, *5*(4), 120–129.

Kapp, K. M. (2012). *The Gamification of learning and instruction: Game-based methods and strategies for training and education*. San Francisco, CA: Pfeifer.

Kuflik, T., Stock, O., Zancanaro, M., Gorfinkel, A., Jbara, S., Kats, S., Sheidin,J., & Kashtan, N. (2011). A Visitor’s guide in an active museum: Presentations, communications, and reflection. *Journal on Computing and Cultural Heritage*, *3*(3), 1–25. doi:10.1145/1921614.1921618

Kuo, C. W., Yang, J. M., Lin, Q. P., & Chang, M. (2009). E-learning: The Strategies of learning culture and arts. *Lecture Notes in Computer Science*, *5670*, 101–107.

Lien, Y. N. (2015). Mobile edutainment system – National Palace Museum as an example. In *Proceedings of Future Internet of Things and Cloud* (pp. 597-601). Rome, Italy: IEEE.

Mora-Guiard, J., & Pares, N. (2014). “Child as the measure of all things”: The Body as a referent in designing a museum exhibit to understand the nanoscale. In *Proceedings of conference on Interaction design and children* (pp. 27–36). doi:10.1145/2593968.2593985

Nunnally, J. C. (1978). *Psychometric theory* (2nd ed.). New York, NY: McGraw-Hill.

Packer, J. (2006). Learning for fun: The Unique contribution of educational leisure experiences. *Curator: The Museum Journa*l, *49*(3), 329–344. doi:10.1111/j.2151-6952.2006.tb00227.x

Paliokas, I., & Kekkeris, G. (2008). Implementation of virtual museums for school use. *International Journal of the Inclusive Museum*, *1*(1), 11–20.

Paliokas, I., & Sylaiou, S. (2016). The Use of serious games in museum visits and exhibitions: A Systematic mapping study. In *Proceedings of Games and Virtual Worlds for Serious Applications* (pp. 1-8). doi:10.1109/VS-GAMES.2016.7590371

Parsons, S. (2015). Learning to work together: Designing a multi-user virtual reality game for social collaboration and perspective-taking for children with autism. *International Journal of Child-Computer Interaction*, *6*, 28-38. doi:10.1016/j.ijcci.2015.12.002

Pasek, Z. (2008, June). *We got games: Informal technology education in a hands-on museum*. Paper presented at the ASEE Annual Conference and Exposition, Pittsburg, PA.

Paul, F. C., Goh, C., & Yap, K. (2015). Get creative with learning. In *Proceedings of Conference Extended Abstracts on Human Factors in Computing Systems* (pp. 81–84). New York, NY: ACM. doi:10.1145/2702613.2728657

Pelay Orozco, M. (1978). *Oteiza. Su vida, su obra, su pensamiento, su palabra* [Oteiza. His life, his work, his thoughts, his word]. Bilbao, Spain: La Gran Enciclopedia Vasca,

Pelletier, C. (2008). Gaming in context: How young people construct their gendered identities in playing and making games. In Y. Kafai, C. Heeter, J. Denner, & J. Sun (Eds.), *Beyond Barbie and Mortal Kombat: New perspectives on gender and gaming* (pp. 145-160). Cambridge, MA: MIT Press.

Pescarin, S., Pietroni, E., Rescic, L., Wallergard, M., Omar, K., & Rufa, C. (2013). NICH: A Preliminary theoretical study on natural interaction applied to cultural heritage contexts. In *Proceedings of the Digital Heritage* (pp. 355–362). Marseille, France: IEEE. doi:10.1109/DigitalHeritage.2013.6743760

Petridis, P., Dunwell, I., Liarokapis, F., Constantinou, G., Arnab, S., De Freitas, S., & Hendrix, M. (2013). The Herbert virtual museum. *Journal of Electrical and Computer Engineering*, *2013*, 1-8. doi:10.1155/2013/487970

Prensky, M. (2005). Complexity matters. *Educational Technology*, *45*(4), 1–15.

Rehm M., & Jensen L. (2015). Accessing cultural artifacts through digital companions: The Effects on children's engagement. In *Proceedings of Culture and Computing* (pp. 72-79). Tokyo, Japan: IEEE. doi:10.1109/Culture.and.Computing.2015.44

Rivera-Gutierrez, D., Ferdig, R., Li, J., & Lok, B. (2014). Getting the point across: Exploring the effects of dynamic virtual humans in an interactive museum exhibit on user perceptions. *IEEE Transactions on Visualization and Computer Graphics*, *20*(4), 636–643.

Roussou, M., & Ave, M. (2007). Children designers in the museum : Applying participatory design for the development of an art education program. In *Proceedings of international conference on Interaction design and children* (pp. 77–80). New York, NY: ACM. doi:10.1145/1297277.1297292

Salen, K., & Zimmerman, E. (2004). *Rules of play*. Cambridge, MA: The MIT Press.

Schieck, A. F. G., & Moutinho, A. M. (2012). ArCHI: Engaging with museum objects spatially through whole body movement. In *Proceedings of the 16th International Academic MindTrek conferenc*e (pp. 39-45). New York, NY: ACM. doi:10.1145/2393132.2393141

Şen, F., Díaz, L., & Horttana, T. (2012). A Novel gesture-based interface for a VR simulation: Re-discovering Vrouw Maria. In *Proceedings of International Conference on Virtual Systems and Multimedia* (pp. 323–330). IEEE, Milan, Italy. doi:10.1109/VSMM.2012.6365941

Sharples, M., Adams, A., Alozie, N., Ferguson, R., FitzGerald, E., Gaved, M., & Roschelle, J. (2015). *Innovating Pedagogy 2015: Open University Innovation Report 4.* The Open University. Retrieved from http://oro.open.ac.uk/id/eprint/45319

Shoemaker, G., Tsukitani, T., Kitamura, Y., & Booth, K. S. (2010). Body-centric interaction techniques for very large wall displays. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries* (pp. 463-472). New York, NY: ACM. doi:10.1145/1868914.1868967

Siemens, G. (2005). Connectivism: A Learning theory for the digital age. *International Journal of Instructional Technology and Distance Learning, 2*(1), 3-10.

Sylaiou, S., Liarokapis, F., Kotsakis, K., & Patias, P. (2009). Virtual museums, a survey and some issues for consideration. *Journal of Cultural Heritage*, *10*(4), 520–528. doi:10.1016/j.culher.2009.03.003

Taxén, G. (2004). Introducing participatory design in museums. In *Proceedings of conference on Participatory design* (pp. 204–213). New York, NY: ACM. doi:10.1145/1011870.1011894

Urtasun Pineda, A. (2006). *Guía para educadores* [Guide for teachers]. Pamplona, Spain: Fundación Museo Jorge Oteiza Fundazio Museoa. Retrieved from http://www.museooteiza.org/wp-content/uploads/2007/09/irakasle_gida06_es2.pdf

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. *Journal of Computers & Education*, *53*(2), 286–299. doi:10.1016/j.compedu.2009.02.007

Wishart, J., & Triggs, P. (2010). MuseumScouts: Exploring how schools, museums and interactive technologies can work together to support learning. *Journal of Computers & Education*, *54*(3), 669–678. doi:10.1016/j.compedu.2009.08.034

Yiannoutsou N., Anastasaki S., Mavini C., Manoli V., Dimaraki E., Avouris N., & Sintoris C. (2014). On establishing contact with cultural objects: The Role of a location based game in supporting visitors to engage with contemporary art. In *Proceedings of Interactive Mobile Communication Technologies* (pp. 290-295). Thessaloniki, Greece: IEEE. doi:10.1109/IMCTL.2014.7011150

Yoshida, R., Egusa, R., Saito, M., Namatame, M., Sugimoto, M., Kusunoki, F., Yamaguchi, E., Inagaki, S., Takeda, Y., & Mizoguchi, H. (2015). BESIDE: Body Experience and Sense of Immersion in Digital paleontological Environment. In *Proceedings of Conference Extended Abstracts on Human Factors in Computing Systems* (pp. 1283–1288). New York, NY: ACM. doi:10.1145/2702613.2732824