A Serious Game Model for Cultural Heritage

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Serious games present a promising opportunity for learning, but the genre still lacks methodologies and tools for efficient and low-cost production, particularly for teacher and domain experts. This article gives an authoring framework that aims to provide structured support, from content design to final implementation. In particular, we have abstracted a conceptual model—the SandBox Serious Game - which relies on a generalization of task-based learning theory. The model invites players to perform cognitive tasks contextually while exploring information-rich virtual environments. We consider it particularly suited for cultural heritage entertainment applications. The model defines games that are set in realistic virtual worlds enriched with embedded educational tasks, which we have implemented as minigames. This approach simplifies the authoring work, which can easily be supported by visual authoring tools for ontology-based urban 3D modeling and implementation tasks, thus allowing an approach similar to the mind-maps concept. We propose a top-down methodology for content preparation, starting from a city-level analysis down to the single points of interest and associated tasks, which are instances of simple predefined minigame/quiz typologies. We provide examples and discuss criteria for selecting task typologies according to the authors' cognitive targets. Finally, we discuss the results of a user test, which took place in a lab, aimed at verifying the acquisition of cultural heritage knowledge in a pleasant and engaging way. Games appear particularly suited for supporting the study of images, especially of iconography. Compared to reading text, a game forces the player to focus more strongly on problems, which favors knowledge acquisition and retention. Learning complex concepts requires an investigative attitude, which can be spurred by well-designed games. Good design involves usability, graphic appeal, appropriate content, and the presence of connections which a player must discover in the content. Players should be asked to pay attention to and reason about their whole game activity - including the relationships between the game content, the brief introduction, and concluding texts. More comprehensive tests are needed to better investigate the educational effectiveness—however, the first results are promising, especially in terms of user motivation and creation of new opportunities for learning about CH.

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1. INTRODUCTION

Serious games (SGs), a class of games whose primary goal is not entertainment [Gee 2003; Prensky 2003; Greitzer et al. 2007], are attracting growing interest from educators [De Grove et al. 2010]. By exploiting the latest simulation and visualization technologies, SGs are able to contextualize the player's experience in a stimulating and realistic environment (situated cognition) [Van Eck, 2006]. Dale's Cone experience model claims that students can only remember 10 percent of what they read, but almost 90 percent when they perform a task [Dale 1969]; and furthermore a large and growing population is familiar with playing games.

SGs also look like a promising tool in the field of cultural heritage (CH) [Foni et al. 2010]. In this article we explore how to exploit SGs in this domain, targeting a general audience, since we believe that SGs can be a powerful tool for inviting people who are not familiar with art and culture to discover the beauty of their artistic heritage. On the one hand, good SGs heighten the players' sensations in immersive situations by providing concrete, compelling contexts in which players can become concretely involved. This is valuable, particularly for CH, where objects in museums are often decontextualized, and thus more difficult to appreciate [Economou 1998]. On the other hand, CH artifacts can represent an interesting context for adventure and exploration. Thus, SGs may embed a lot of meaningful contextualized information.

The present work intends to exploit already available basic technology building blocks so that teachers and CH experts themselves can address the emerging issue of how to efficiently translate CH content into pleasant and educationally effective games [Greitzer et al. 2007]. We have explored this issue in the development of an SG, namely Travel in Europe (TiE), as an innovative means for the promotion and development of European CH. The TiE SG exploits the concept of travel, which is an engaging invitation to knowledge acquisition, and also exploits geographic contextualization. TiE travel takes place via faithfully reconstructed virtual reality 3D reconstructions of today's European cities, in which users are challenged to explore and discover local history, art, and customs. The game relies on exploring urban spaces and manipulating (via tasks/minigames) the insertion of tasks inside game activities, which has become common in SG design (e.g., Maciuszek and Martens [2012]) for the virtual representation of heritage artifacts. This pedagogical approach was chosen—among other possibilities for presenting multimedia information on heritage—in order to involve users who are not keen on cultural activities while being fond of videogames.

In this article we focus on a special class of SGs, the Sand-Box Serious Games (SBSGs). SBSGs, as we will describe in the next section, invite players to perform cognitive tasks contextually, while exploring information-rich virtual environments. In principle, this class looks particularly suited to SGs for CH. But for a proper analysis, and before extensive end-user tests, there are a number of questions to be answered: How can an effective SBSG be modeled, both in terms of a 3D environment and tasks? Which types of tasks are most suited to deliver which contents? Can a methodology be devised for implementing an SBSG for a given city heritage? Hence the innovation in this article is not so much in the technical implementation (this was addressed in previous publications ([Bellotti et al. 2009a, 2009b, 2011]), as it is in the analysis, including testing users for how to efficiently design a SBSG to support promotion and discovery of CH to ensure a proper coverage of artistic masterpieces.

The reminder of the article is organized as it follows: Section 2 introduces the concept of Sandbox Serious Games, while Section 3 presents an overview of related work. In Section 4 we deal with the issue of efficiently building 3D urban environments for CH. Section 5 presents the task typologies we have studied in our work, while Section 6 provides a case study. Methodological aspects on how to organize the contents for a CH application are discussed in Section 7. Section 8 discusses the use of the various task typologies, while Section 9 analyzes the results of a lab user test aimed at verifying CH knowledge acquisition in a pleasant and engaging way. Section 10 draws the conclusions on the work done.

2. SANDBOX SERIOUS GAMES

The SBSGs concept [Squire 2008; Bellotti et al. 2010a] relies on research on cognitive processing—how information is stored, retrieved, and represented [Atkinson and Shiffrin 1968; Tulving 1972] –, that stresses the importance of helping students to develop well-connected knowledge structures representing relationships among facts and concepts. When the knowledge structure for a topic is well-connected, new information is more readily acquired because the cognitive load is low [Greitzer et al. 2007].

Thus, when developing interactive applications that aim at knowledge acquisition and skill development, it is necessary to design a proper cognitive-supporting structure. A paradigm can be abstracted, via the analysis of effective SBSGs, which tends to provide players with a suitable knowledge structure for the targeted topic. In rough terms, the model consists of

—a concrete spatial organization - the virtual world (VW) of the game – where knowledge is distributed;

—tasks that are spread in the VW. Tasks are simple activities that embody units of knowledge which can be discovered by the user and played in order to construct meaning, build lasting memories and/or deepen understanding [Bellotti et al. 2010b].

An extensive use of tasks relies on task-based learning (TBL) pedagogical theory [Willis 1996; Willis and Willis 1996], which stresses the importance of concrete, focused activities to develop knowledge and skills. Tasks are activities characterized by the ability to engage the learner's interest; a primary focus on meaning; a need for completion; an outcome in terms of which success is judged; and a clear relationship with real-world activities [Willis 1996]. TBL concerns language instruction [Ellis 2003], but we generalize the term to videogame tasks, which are activities that provide the same features but are not restricted to the language domain.

In our research we have implemented an SBSG platform that allows multiplayer online gaming in 3D environments and interaction with players' avatars and virtual characters [Bellotti et al. 2009a]. In our model, tasks can be annotated pedagogically. Authors annotate tasks by adding semantic-relevant metainformation about their types, content, supported user-learning styles, and so on [Bellotti et al. 2010b]. This allows decoupling the tasks, which can be reused in different SGs from the definition of their delivery strategy in a specific SG, which is specified by the SG designer (who is not the content/task author), and automatically managed by a runtime engine, the experience engine (EE), as we see in Section 5.

Tasks are implemented as minigames that focus the player's attention on a particular item that he or she may find during his virtual exploration in the game environment. Sample tasks are inspired by well-known simple game models, such as *Puzzle*, *MemoryGame*, and *FindTheWrongDetails*. The idea, in fact, is that they should be made immediately playable, so that the player can focus on the content rather than on learning how to play. In order to provide consistent and homogeneous interaction modalities (which can be quickly and easily learned by the player and then used several times), we have defined a library of task templates. Every task in the VW is an instance of one such template (typology). This approach also simplifies authoring work and makes it more efficient, allowing reuse of tasks in different SGs, thanks to the availability of an authoring toolkit which allows easy instantiation from the templates [Bellotti et al. 2010b]. We describe task typologies in detail in Section 5.

3. RELATED WORK

The use of SGs for CH applications has been explored in several projects, and several initiatives have been carried out, from which we highlight a special interest group (SIG) devoted to CH and the

humanities in the new EU-funded Network of Excellence dedicated to Serious Games.[1] Falk Anderson et al. [2010] provide the most complete field survey to date. They divide the domain in three areas: prototypes and demonstrators, virtual museums, and commercial historical games. In the first area, they highlight the Rome Reborn Project, which aims at producing a high-resolution version of Rome in 320 AD [Frischer et al. 2008]; the Ancient Pompei project [Maim et al. 2007], which simulates a crowd of Romans, who behave realistically, in a district of Pompeii; and the Parthenon Project [Stumpfel et al. 2003], which built a virtual version of the Parthenon and its sculptural elements. Virtual museums include the Virtual Egyptian Temple game [Jacobson and Holden 2005], set in a hypothetical temple depicted with all its key features; a set of games associated with the Olympic Games by the Foundation of the Hellenic World, which provides the possibility of visiting several historical sites within gameplay [Gaitatzes et al. 2004]; and the Priory Undercrofts SG, based on a reconstruction of the Benedictine monastery in Coventry (UK), which relies on the work of archeologists; and finally, commercial historical games including History Line 1914–1918 (the pioneer work, dating from 1992); Great Battles of Rome (3D tactical simulation); and the popular Total War.

An interesting SG has been published more recently, it is set in a virtual reality reconstruction of an Italian city in the Middle Ages [De Paolis et al. 2011]. This work is similar to TiE because it involves visiting points of interest in a virtual world; but it differs significantly in that that it does not include the concept of task.

All these projects highlight the relevance of SGs as a means for promoting CH to a wide audience. However, in order to move SGs from pilot and research projects to products suitable for large audiences, efficient frameworks and models that support content creation are needed [de Freitas et al. 2009]. Particularly major problems are the huge development costs and limited reuse (apart from the virtual reality models, which may be used in various SGs). The technology enhanced learning (TEL) literature already includes some examples of authoring support through graphical tools that define the behavior of 3D objects as a combination of basic behaviors (patterns) [Pellens et al. 2008]. Higher-level tools are, however, needed to support the design from the point of view of the cultural heritage expert. Approaches from this direction are based on ontologies and semantics [Tutenel et al. 2008] in order to give operational meanings to the objects in the VWs. This allows authors to focus better on the specifics of the cultural domain [Vanacken et al. 2007]. We have addressed this issue by resorting to a generalization of the task-based learning pedagogical approach, using annotated tasks as reusable game mechanisms suited for focused, situated learning.

Inserting tasks into an environment which is to be explored can be seen as a SG mechanism to support knowledge acquisition. Other methods include, for instance, interactions of players with nonplayer characters (NPCs) [Zielke et al. 2009; Swarz et al. 2010]; simulations of activities/systems [Doucet and Srinivasan 2010]; and interplayer competition and socialization. Unlike the preceding examples, task-based learning represents a specific, highly replicable model for delivering various types of content.

In a sense, our approach (described in detail in Section 6) can be thought of as "virtual geo-caching," which is the outdoor activity of hiding an object in a particular position, then publishing its coordinates and letting players find it by exploring the environment [O'Hara, 2008]. In our system, the space to explore is a 3D virtual world.

An important aspect of SGs consists in the personalization of content. The literature is rich on information for modeling users and visitors in CH applications, such as museum guides [Kuflik et al. 2011] and museum learning technologies [Antoniou and Lepouras 2010]. Our approach is a general one for learning, and relies on a user model [Bellotti et al. 2009c] that is used by the EE to match the task meta-data and to adapt the task parameters, as described in Section 5.

[1]www.galanoe.eu.

Authoring support is a significant part of the model we propose. Related approaches are e-Adventure [Torrente et al. 2010] and StoryTec [Göbel et al. 2008]. The first is a teacher-oriented authoring tool that abstracts the common traits of adventure games in order to support the development of such games. The visual editor is very powerful, but is focused on the point-and-click 2D adventures game genre, while our task-based concept is usable in a 3D virtual world as well as in other genres (e.g., first-person, strategy, puzzle games, and so on). The StoryTec system, developed in the context of the 80Days project [Göbel et al. 2009], allows the user to setup a game story (based on models or from scratch) by defining a set of scenes (2D or 3D worlds populated with object and actions) with their transitions. The story editor is quite complex and powerful, similar to commercial game environments, like the Unity Game Engine. For instance, objects can be dragged from a resource folder and dropped in a scene. Our authoring tool does not apply to 3D scenes, for which we use the standard game engine tools, but supports the instantiation of minigames focussed on CH items and topics.

Some SGs are characterized by a high non-player character (NPC) interactivity. An example case is given by Façade, an interactive drama played from a first-person viewpoint. The Façade architecture [Mateas and Stern 2005] relies on a character authoring language and a drama manager to build interactive experiences based on natural language dialogue. Our approach is complementary, and for the future, we are interested in exploring adding highly interactive NPCs to the proposed SBSG format.

4. VIRTUAL ENVIRONMENTS FOR CULTURAL HERITAGE SBSG

The SBSG paradigm (i.e., a player's exploration of a virtual environment and the performance of localized tasks) looks promising for the CH domain, since a user can discover and interact with artistic artifacts while exploring a contextual world in an adventure-like fashion.

In particular, the paradigm seems to meet two major technical and user/stakeholder requirements. First, it implements a 3D reconstruction of a city or a region for education/cultural goals within an interactive environment (e.g., a serious game). This is a process that requires a careful trade-off between the photorealism of 3D models, which is necessary to provide a highly impressive, culturally correct, and meaningful experience, and the need for interactive real-time online exploration. Second, complex VWs are costly to implement, both for modeling the 3D structure itself and for taking pictures, rectifying and equalizing them, and composing the final textures to be managed by the graphic engine at run-time.

In a highly interactive system, such as a 3D exploration/game, displaying the details of the reconstructed environment is not fundamental, as there the player moves rapidly. However, in the case of a CH game, the player, playing as a sort of art detective, has to also examine the particulars, where relevant. In order to meet the requirements stated above, we investigated the reconstruction design of each covered place (e.g., a city or areas inside a city), according to the following high-level rules.

—The 3D model is completely geo-referenced. The ground is taken from a local 2D vector map, so placement of the buildings in the model is precise. This also allows exploiting synergies with open geographic information systems (GIS) APIs (e.g. Google Maps and Microsoft Virtual Earth), which are now commonly exploited in combination with Web 2.0 technologies to build location-based services. As a basic implementation, the TiE models now integrate a 2D map interface where the position of the player is shown in real-time on the corresponding real city map.

—In each covered area, a few points-of-interest (PoIs) are implemented (Figure 1(a)). These buildings are rigorously reconstructed with a high level of detail. We use this approach for culturally meaningful buildings such as cathedrals, theaters, and so on.

—The textures for all the other palaces are built via a statistical ontology-based algorithm. Since several zones within a city are typically characterized by relatively homogeneous buildings (one or a

(a) (b)

Fig. 1. (a) Sample of two PoIs (Palazzo Rosso on the left and Palazzo Bianco). (b) Sample of a style area in the city of Genoa.

few building styles), the idea is to exploit a statistical description of the architectural parameters (e.g., types of windows, roofs, number of floors, are organized in an ontology defined on the basis of existing architectural grammars such as that of Stiny, [1975]) and create the building textures by statistically assembling architectural components representative of that area. We have implemented this concept via the Architectural Style Area (ASA) algorithm, which is the basis of the Urban Creator visual tool [Bellotti et al. 2011], through which a content developer can (1) specify the building models for an urban area and the statistical distribution of the architectonic parameters; and (2) insert the relevant textures. The tool processes the input to produce the ASA 3D model of the area (e.g., Figure 1(b) and background palaces in Figure 1(a)).

With this approach, the effort to cover extended urban areas is reasonably manageable and the reconstructed environment allows users live experiences which are similar to an actual visit to a city, where a visitor typically has the feeling of being in a precise place but does not usually perceive/remember the details of each distinct building. We say this approach as based on the "architectonic-style likelihood" principle.

Compared to the state of the art, the ASA method is less demanding than Façade in terms of input data modeling techniques (e.g., Mueller et al. [2006]), as it requires only the pictures corrected by the sample elements and an estimate of their distribution, whereas Façade modeling methods need hundreds of input pictures in order to collect information on all the buildings in the area. However, Façade modeling seems to outperform both ASA and Procedural modeling (e.g., Sun et al. [2002]) in terms of realism. Compared with Procedural modeling, ASA is simpler to customize for a city, as it only needs a statistical description, whereas the set of rules needed by Procedural methods to generate shapes may vary greatly among cities [Bellotti et al. 2011].

Instead, the PoIs that are expected to be the subjects of a more exacting analysis by players are reconstructed at a high level of detail and with their own specific textures (i.e., not statistically defined). While several virtual worlds (VWs) represent urban landscapes, a significant drawback to their use is that monuments are key features in an urban environment but are awkward to reconstruct. Currently, there are two major approaches for modeling monuments. The first one consists in the actual polygonal reconstruction of the monument, and is mostly used for cultural reconstructions. The resulting model can be very precise, but achieving high quality usually requires defining a huge number of polygons, which are heavy to load at run-time, and such a model takes time to build [Patias 2007].

Fig. 2. Set of pictures for the enhanced billboard modeling of a monument.

The second approach is the billboard, which was developed to represent natural trees in videogames. This solution is mostly used in real-time videogames, which cannot afford long loading (and model development) times, and consists in attaching a photo of the monument to a flat plane that is continuously rotated by the system so that it is always in the player's frontal view. This limits the realism and the quality of the implementation, and is not suitable for to a cultural experience.

In order to overcome these drawbacks, we have tried to apply a procedure based on an enhancement of the billboard approach, consisting in the use of multiple textures (photos of the monument) which are displayed at different viewing angles. This keeps the simplicity of implementing the monument as a flat plane, but allows seeing different pictures from different viewing angles, instead of always looking at the same picture, independently of the angle of view. For each monument, it is necessary to provide a set of N pictures taken with the camera's line of sight perpendicular to the monuments and spaced every (360/N) degrees on the equator line (Figure 2). A preliminary test showed that the minimum number of pictures to give a meaningful idea of the monument is $N = 4$, corresponding to the 4 main directions. The monument can be thought of as surrounded by a sphere and the digital camera placed in N positions on the sphere's equator. The lenses of the camera are directed towards the center of the sphere. In this way, we keep the development of 3D models for monuments within a short timeframe and allow VW explorers to have a reasonable view.

This approach represents a new use of a standard videogame technique (multiple texture billboarding) as a simple and efficient technique for authors such as teachers and CH experts to easily produce usable content.

5. TASK TEMPLATES AND TOOLS FOR AUTHORING

5.1 Task (Minigame) Typologies

This section gives an introduction to the task typologies that we have implemented in the platform as software templates. The task typologies are easy and most of them are adapted from "paper and pencil" quizzes or simple, popular computer games. For this reason we call them minigames as well, even if the concept is more general. We broadly divide them in three categories, according to the cognitive skills they mostly involve (Table I).

Table II lists the task templates we have implemented. Section 8 ("Exploiting task typologies") gives a detailed analysis, discusses some examples for the potential of task typologies and how they fit different types of CH educational needs and perspectives.

Table I. Task Template Categories

Category	Description
Observation tasks	These tasks/games privilege sight for investigating and exploring the local environment. In general, these games tend to exploit "knowledge in the world" in order to develop cognition [Dickey 2003; Ducheneaut et al. 2006]. They aim to stimulate spatial processing skills. Such skills are important in cognitive development since they allow creation of meaning by manipulating visual images [Pillay et al. 1999; Kahana et al. 1999].
Reflection tasks	These tasks/games tend to favor reflection, analysis of questions and possible answers considering the clues available in the neighborhood and concepts learned previously during the game.
Arcade tasks	These tasks/games stimulate similar skills as observation games do. Their specificity lies in the animated graphics and engaging interaction, which helps create a convincing and pleasant experience. They stimulate fantasy and evoke images and atmospheres that can be used to convey educational messages which are easily memorized by players.

5.2 Task Parameterization

A fundamental feature of task templates is that they are parametric. Every task instance is described by an XML configuration file that specifies the values of the instance's parameters. The configuration file is prepared by the pedagogical or domain-expert author via an easy-to-use visual authoring toolkit (AT). This allows educational experts who are not familiar with programming to create new task instances. Parameters involve content (i.e., text, images, difficulty levels, etc.); timing (of questions and answers); and multimedia display (i.e., buttons, sounds, fonts, colors, etc.).

Some important parameters concern learning mechanisms, and are used in computing a score, which is key for competition and game level advancement. Thus, the way in which rewards and penalties are computed is fundamental in encouraging or discouraging some player behaviors. Typical parameters we use for minigame score computation are the time elapsed, number of help requests, and the number of steps/moves to arrive at the solution. In fact, these are the factors we usually consider when evaluating a student. Since an author may reward precision (e.g., minimal number of moves in solving a puzzle game) more than speed in accomplishing a task, in order to invite players to an accurate rather than fast analysis of the topic, we let the author set the overall score as a weighted sum of the scores obtained by measuring a player's performance in terms of time and accuracy, as we see in the example in Figure 3.

Some parameters can be managed automatically by the run-time system, in order to increase the usability range of the game, thus enhancing the possibility of its reuse [Bellotti et al. 2009b]. For instance, the difficulty level of a task could be dynamically adjusted. In a *puzzle* game, the number of pieces is decided dynamically based on the level of the player. Similarly, quizzes can reduce the number of possible answers presented to the player.

Table III shows the main parameters of the Puzzle minigame template. The number of rows and columns can be changed automatically by the run-time system for the sake of adaptivity. Figure 3 shows some parameters that an author has to set to define the score values for accuracy and time performance.

5.3 Tools for Authoring

VWs are 3D settings that lend themselves to different uses by a player: free wandering, competition, and training. Our approach proposes to enrich the virtual environment with embedded tasks that can provide the player with more information and learning/testing opportunities. As instances of templates, tasks can be produced on a large scale. This explains the expected benefits coming from the availability of a system that supports efficient authoring, that is, the authoring tool (AT).

Table II. Description of Task Templates

Name	Description	Cognitive aspects
Manuscript (Reflection)	The player must insert missing words in a text document. He/she can choose the possible alternatives from a dropdown menu. In a slightly more difficult case, the player has to first identify wrong words in the text and, once identified, select the alternative.	Reasoning about text and language; evaluation of alternatives.
Image comprehension (Observation)	The player must answer a list of questions related to an image (e.g., who are the people in the picture? What is the symbolic meaning of a detail/the whole picture?). The multiple answer questions appear beside the image.	Observational skills; understanding images; reflection; analysis of questions and search for possible answers; iconographic analysis (training the player in the interpretation of a picture and its details).
Contextualized questions about a picture (Observation, Reflection)	The player must explore an image with a wand tool. In some areas the wand pop-ups a question related to underlying image detail and the player must answer it among multiple choices in a short time.	Observation skills; understanding images; attention to detail; critical reasoning; speed of reflexes; analysis of icons.
Quiz, VisualQuiz (Reflection)	This is a simple multiple-choice list of questions. The question is generally tied to its location in the VW. Samples include historical quizzes, guessing games, local dialect/language quizzes. A version with images instead of written questions/answers is also available (VisualQuiz). The user has to click on the right answer in the text or image.	Reflection; analysis of questions and possible answers considering available clues and concepts previously learned; evaluation of alternatives; memory; critical reasoning.
Wrong or missing details (Observation)	The player must detect all details that have been deleted or added to an image. The user clicks on them until all are found (or he/she pushes the exit button). Immediate feedback is provided.	Analysis of the image; observation of and focus on details; iconographic analysis.
RightPlace (Reflection, Observation)	The player must move (by dragging-and-dropping) several icons in their right places over an image representing a geographic or conceptual map. The icons are initially placed in a column to the right of the map. Placements can be overridden by dropping a new icon in that place. Feedback is provided at the end of the game.	Observation; critical reasoning; matching; map comprehension; mental map generation.
Puzzle (Observation)	The player must compose an image (e.g., a façade of a palace) by dragging its rectangular pieces which initially appear randomly distributed, and dropping them in the target position. Feedback is only provided at the end. Help is available (once a piece is positioned in its right place). The player may have seen the relevant item during his exploration or may be playing just in front of the 3D model.	Observation skills; memory; ability to identify geometrical patterns; attention on colors and shapes.
Couples (Reflection, Observation)	The player must match the items in the right column with those on the left by pointing and clicking. A connection can be deleted (by clicking on one of its two images). Feedback is provided only at the end (right, wrong, and missing connections). Help is available (one right connection is displayed).	Observation; critical reasoning; matching; image comprehension.
CatchIt! (Arcade)	On a 2D cartoon background, a nonplayer "launcher" character throws objects from a tower/balcony. The player moves a "catcher" character (with the left and right key arrows), who has to catch the "right" objects and avoid the "wrong" ones.	Promptness of reaction; observation.

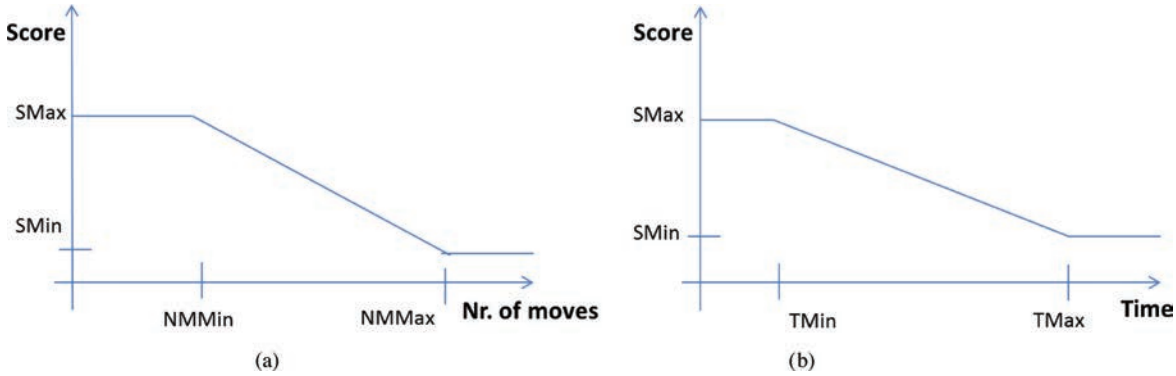

Fig. 3. Parameters for score computation in terms of accuracy (a) and timing performance (b).

Table III. Parameters for the *Puzzle* Minigame Template

Parameter	Description
Number of rows	Number of rows into which the image is divided in the game.
Number of columns	Number of rows into which the image is divided in the game.
Max number helps	Maximum number of helps that a player can request (or is provided automatically). The help consists in the fact that the system puts one piece in its right place.
Help timeout	Timeout after which a help is provided automatically.
Help cost	Score value detracted from the final score for each help given.
Deadline	Maximum playtime length.
Accuracy assessment weight (Aaw)	The final score is the weighted sum for accuracy assessment and time performance assessment. An author (teacher) may reward accuracy more than completion speed, penalizing a "trial and error" approach by the player and inviting him or her to a more reflective behavior. Figure 3 shows the parameters set for computing the scores for accuracy and time performance.
Time assessment weight (Taw)	The relative weight (expressed as a percentage) of time performance assessment. The sum of Aaw and Taw is 100%

With a potentially large number of embeddable contents/tasks, it becomes important to define strategies for providing single users with the most suitable tasks during exploration of the VW. This requires defining a model of the task, a model of the user, and a model of the target learning strategy. In order to allow for this, the AT supports the author's annotation of created tasks with metadata that specifies the pedagogical features of the task and the PoI to which it is related [Bellotti et al. 2010a]. Typical task metadata includes types, contents, supported user learning styles, and positions; while user data includes learning styles, task type preferences, content preferences, and performance [Bellotti et al. 2009c].

This allows an artificial intelligence (AI)-based run-time management system, namely, the experience engine (EE), to deliver tasks dynamically during a game session to support the acquisition of personalized knowledge [Bellotti et al. 2009b]. In particular, the EE's AI learns an appropriate task-scheduling policy whose requirements are specified by the author via the AT, exploiting the user and task models. For instance, a teacher could prepare a game with tasks that stress the weakest learning style of each player (e.g., by providing a balanced mix of Flemish and Venetian paintings, or by fixing a performance improvement target). With this approach, the domain-expert author focuses on

Fig. 4. Snapshots from the TiE 3D reconstruction of Genoa and Prague.

characterizing tasks, on the expected learning curve, and on user needs, while the task sequencing, which takes the real user profile and runtime interaction into account, is delegated to the EE.

This paradigm of preparing a large database of reusable tasks is particularly useful for an efficient production of games (for instance, in several different places of cultural relevance).

All the details of the Toolkit—functionalities and pedagogical foundations—are provided in Bellotti et al. [2010b]. This article focuses on how to develop tasks for CH applications, based on our working experience, also informed by informal tests in labs and high schools, with students and teachers, and focus groups with pedagogical and art/history experts.

6. THE GAME EXPERIENCE

The developed platform—built atop of the Torque 3D game engine—provides a flexible framework which can be used to implement a number of SG applications with different types of content. In the TiE project, we have explored a treasure hunt game model, and developed city examples from several EU cities: Genoa, Strasbourg, Prague, Cluj, Maribor, Plovdiv, Tomar, Arousa Norte, and so on. We now aim to create a community of users and educators who will be able to continuously grow the system database.

6.1 The Treasure Hunt Model

When developing an SG, besides possessing content (virtual environments, tasks), it is necessary to identify the game context and plot in order to make it appealing. Considering the nature of the proposed platform, which favors creation of tasks and their contextualization (placement) at suitable positions in an urban 3D environment, we thought of a treasure hunt game plot, since it would promote discovery in a city context, with ever-new content available to players without need to change the software. Instances of minigames can, in fact, be easily produced by CH domain experts and used as challenges at appropriate stages of the treasure hunt.

The plot of the treasure hunt game is simple and schematic; but it represents a format that is scalable and flexible in terms of content, which could be developed cost-effectively and could also be used by third parties and in a user generated content (UGC) context as well through the AT. Teachers/experts could also control the tasks available for a game by simply specifying those available in every city.

Also a simple, easy to understand structure—coupled with minigames created as instances of templates whose interaction modalities can be easily learned once by a player and applied in several different cases—poses little cognitive overload for the player, who can effectively focus his attention on the content and context.

There is a risk that the player may have a "clunky" experience, since the author is not required to specify a complete narrative. However, SandBox-like games are successful in the market where the player builds his own narrative experience by interacting with contextualized situations and miniadventures during exploration of a wide geographic environment (e.g., Oblivion and Grand Theft Auto). The game author specifies such situations and the game's general reward/competition mechanisms, not the details of the plot. According to user tests, introducing tasks in SeaGame has led to levels of player satisfaction not statistically different than state of the art videogames [Bellotti et al. 2009a].

6.2 The TiE Game

In the TiE game, the player has to visit a certain number of cities across Europe, completing a mission in each one of them. A mission is characterized by a number of general questions, which the player should try to answer while exploring the city. (This is useful for giving the player a cultural context for his visit.) In order to answer the questions, the player's avatar explores the faithfully reconstructed urban environments in search of the target places mentioned in the mission; the places are PoIs, such as important palaces and churches. At each target place, the player looks for an icon that triggers the task related to that PoI via a user interface, which we show in Section 6.1. By executing the task, the user can virtually manipulate pieces of the artistic heritage and answer quizzes on the history, art and culture of the PoI. Each task is selected by the EE as the best match between the user model and the available task models according to a defined pedagogical strategy. During the mission, the player can move freely in the city, so orientation and path-finding are major challenges (the city as a sort of labyrinth). Also, in order to favor long-term playability, the task icons at each PoI are always placed by the system in different positions, at increasing levels of difficulty. This also increases exploration by the player in the neighborhood of the PoI. Some topics may not be directly associated with a PoI, and this could be the case for historical facts about the city or the region. In this case, we usually employ a place (e.g., an information kiosk or the city hall) that works as a "gateway" for tasks.

Completion of a mission is verified at the end of the exploration of the city. There is a city-level final test, with quizzes that are related to the mission's questions. Every mission is rewarded with a city prize (e.g., a picture, a symbol) that is stored in the player's repository.

6.3 User Interaction in Tasks

By pointing and clicking on an icon in the proximity of a PoI, the player starts a task session. The user interacts with tasks via a sort of virtual smartphone (Figure 5). We also investigated this method in test sessions with young people and teachers using early prototype versions. Results pinpointed that this interaction modality is appreciated by players. This solution has the advantage of keeping all the player activities inside the virtual world.

This method was devised in order to reduce the splitting effect that a player may perceive between the 3D navigation and the 2D task experience. In fact, the pedagogical idea is that tasks are bound to a geographic position, and hence allow the player to learn more about that place, as typically happens when a tourist stops in front of a church or palace to listen to a guide describing its artistic features.

7. PREPARING CONTENTS FOR A CULTURAL CONTEXT

When developing content for a cultural context (e.g., a city), we proposed a top-down approach, starting from a whole area analysis, which is useful for content developers in fixing the main features to be covered in a game. The choice of PoIs and of the related tasks to be implemented in the area is driven by the need to familiarize the player with the most important elements of the local culture.

Fig. 5. The player can interact with the task through a virtual smartphone.

The first step consists in preparing a table reporting the most important features of the city. Descriptions are structured along dimensions such as geography, history, economy, popular traditions, art, literature, and architecture.

Once the major topics have been outlined, it is necessary to identify the areas in the city that are most suited for conveying the proposed content. This is in order to focus the player on a limited set of relevant areas to be reconstructed in 3D. In each area, the author specifies the main reasons for interest in a particular church, palace, and monument, as they will have to be assigned tasks at the relevant PoIs. In each area, the most interesting monuments, churches, museums, parks, and so on, have to be selected as PoIs, with a description for each of them that specifies the reasons for interest, which will serve as a guideline for defining the tasks to be developed for that PoI.

Finally, for every task/minigame that is deemed useful to implement in a PoI, the author will have to topossible, but text is important for integrating interactivity in the game medium), which will be displayed to the player before and after execution of the minigame as a didactic complement to gaming activity. The introduction is a statement (5 to 15 words) which appears before the start of the task to invite a player to play the minigame (explaining why the featured item is important/ attractive/ etc.). The text must be intriguing and inviting in order to create suspense and expectation. The conclusion is a slightly longer text (10 to 30 words) displayed at the end of the task. Here the idea is to complement with plain text the player's learning activity in the minigame, which should clearly (but briefly) explain the key concept(s) in the task. The introduction, task/minigame, and conclusion should all provide information about the "5 Ws" (who, what, where, when, and why) of the featured item. In general, text has to be meaningful, clear, and deliver well-defined and meaningful concepts because text in a game is barely acceptable to players. This is true for any type of text that is shown to the user in any task.

In the proposed game structure, tasks are seen as a channel to provide content to the players and to test their knowledge as well. Thus, the game database should contain instances of various types of tasks (Table II), and different user skills and learning styles. For instance, some tasks focus on the player's observational or critical reasoning skills and other tasks focus on the promptness of reaction. The idea is to present content from different perspectives and according to the various pedagogical views and objectives of the authors [Bellotti et al. 2010b]. In order to support this, the platform features an experience engine that is able to manage the authors' task annotations, as described in Section 5.2.

In general, we believe that it is important that a virtual tourist should be encouraged to ask meaningful questions about the city: What are the most important historical periods and facts? What are the principal monuments and museums? Who are the most famous artists and personages who worked or lived here? What are the main features of a given artifact? What is there behind a picture? What are the traditional customs? What is the mentality of the people? What is meaningful to the local people? What are the real motivations for their activities? What are their values? How do they show them?

Our system was designed in order to support such questions and the related answers by providing a 3D environment, to be explored by the players, and allowing the embedding of minigames of various typologies. Such minigames can be easily authored, and should allow players to have experiences related to the questions, as we will discuss in Section 8.

The tasks to be implemented by authors should address the questions above so that the players can learn from the answers. The learning philosophy we support is that players should acquire knowledge and domain exploration skills from the quizzes and other tasks (the task typologies were designed to support this approach). Notions (e.g., dates and details of historical events, biographies of historical personages, details of artistic schools) are important because they give players a concrete and clear foundation on which to build knowledge. Tasks should help players discover and become familiar with such ideas. Some tasks should support the investigation of the heritage and territory of a place, while other tasks should test the level of knowledge and skills acquisition. So for every PoI, authors should develop some "exploratory" tasks, from which players can increase their knowledge, and other test tasks where the level of acquired knowledge is tested. Summary tests are usually done at special check points, such as at the end of a visit to a city and/or overall game, and be related to places where the players have actually visited, which is tracked in the user profiles.

8. EXPLOITING THE TASK TYPOLOGIES

A fundamental question when developing tasks for cultural heritage SBSGs is how to translate relevant cultural documents into enjoyable tasks, so that through play a user can acquire as much information as possible about the target topic. Generally speaking, all the tasks typologies are potentially valid for any topic. The criterion for choosing a specific task typology is generally related to the cognitive target that the author wants to propose to the player (Table I). For instance, some typologies are more suited to exploration, others to contextualization, and still others to assessment. Every typology is a different means of representing knowledge. Selection of the means may depend on several factors. For instance, a player may like only a few typologies, or the author may want to insist on the typology where the player is weaker or stronger, or prefer an equal mix. These choices are specified by the game author (or even the teacher using the game) and learned automatically by the EE; this is the responsibility of the run-time task delivery strategy [Bellotti et al. 2009b, 2009c]. The authorial role is fundamental in representing (transmitting) knowledge. The same topic (e.g., a painting by Caravaggio) may be addressed/ in different ways by different means. This multiplies the platform's gaming opportunities (i.e., the same topic may be represented by several different tasks), and makes it possible to play various rounds exploring knowledge and assessing the same topic through different means.

How to best convey cultural information through the proposed task typologies? Let us consider a single cultural area in a city—with one or more PoIs—and discuss how it can be addressed through tasks, highlighting the differences among typologies which may, on first sight, look very similar. Our sample topic is Strada Nuova, a Renaissance street at the very heart of Genoa. It consists of some outstanding palaces built in the 16th century by the leading Genoese banking families. In the next century, three additional palaces were built (Palazzo Rosso, delle Torrette, and Bianco).

When dealing with a cultural topic, several types of documents such as texts, paintings, and so on may be relevant,. In the following we discuss how these types may be used for different tasks

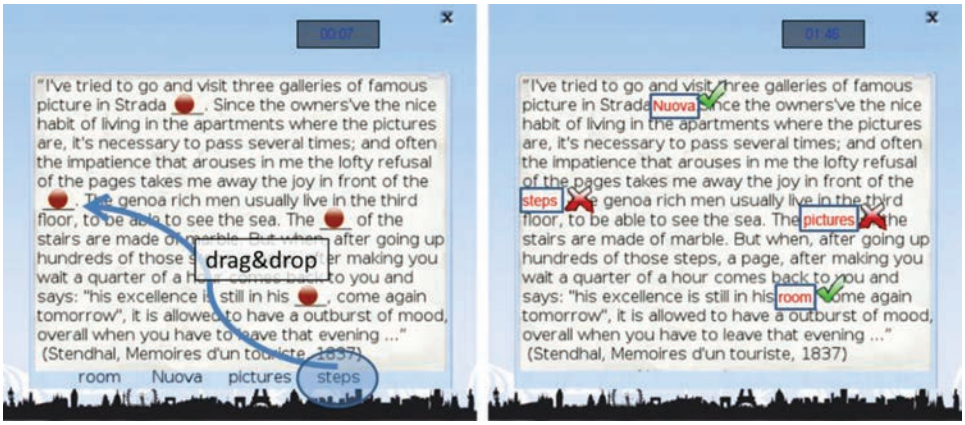

Fig. 6. Manuscript, game page and results.

according to different pedagogical needs. If the author's target is to highlight some words in a text, then the *Manuscript* typology is suitable, as it asks the player to insert missing words in their proper position in the text. For instance, Figure 6 shows a short text by Stendhal, where architectural terms characterizing the palaces on Strada Nuova have been removed. A slightly more difficult task involves replacing target terms removed by the author, instead of leaving blank spaces. In this case, the player has to look for the wrong words in the text and replace them. Examples of words to replace may be synonyms, or words from a completely different topic, and so on. Synonyms, for instance, encourage a detailed literary analysis, highlighting the original words of the author (his style). In general, it is the responsibility of the author to choose the criterion for removing or changing words. For all the game instances, proper introductory and concluding texts are important to focus the user's attention and provide a final explanation and reinforcement. *Manuscript* texts must not be too long so as not to discourage the player (and be designed to match his or her profile). Longer texts may be split into different rounds (i.e., levels) that the player accesses in case of a positive outcome at the previous one.

If the author's target is to highlight the overall concept of a text, the *Puzzle* typology is the more appropriate one. The text excerpt (again from Figure 6) may be used to ask the player to focus on the main message, which is Stendhal's ironic judgment on the owners of the palace, who do not wish to let visitors enter to look at the valuable artistic interiors of the palaces. The use of a *puzzle* as a text is quite original but has an educational intent. The *puzzle*, in fact, requires composing an overall picture, inviting the player to reason about the logic of the text and the combination of its parts. This is particularly true for our implementation, where the score is computed to reward the minimal movement of pieces, and not only the short completion time, in order to favor reasoning over speed.

If the author would like to convey the idea that the Strada Nuova has been visited by enthusiastic and famous writers and artists, a *couple* game would be appropriate, matching the names of the artists with paintings and short sentences about the visit.

Another typology which may be presented in various ways, is that for paintings. *ImageComprehension* allows a complete view of the picture (e.g., style). The list of proposed questions allows the author to draw the user into exploring and reflecting on related items also (e.g., the historical period, the painter). Moreover, questions may be answered in no predefined order, which may allow the player to reflect and obtain hints from the questions themselves.

For instance, the Guido Reni "Assumption" (Figure 7) allows the game author to draw the player's attention to the meaning of the event, the reactions of the participants, the relationships between the

Fig. 7. Guido Reni. Assumption, Chiesa del Gesù, Genoa.

two floors, the meanings of the colors, and so on. Neither *ContextualizedQuestions* nor *Puzzle* (which could have been used with the same image) would have allowed investigation of the various items and their relationships, since *Puzzle* has no links to questions, but proposes a more immediate analysis of the image itself and not of its context, while *ContextualizedQuestions* focuses on the details in the picture.

ContextualizedQuestions is particularly suited for images that are richer in content rather than in artistic value. Several images contain complex texts, and *ContextualizedQuestion* proposes a "full-immersion track" to decode the representation of the image. This task should favor a player's memory by associating it with points in an image.

Figure 8 shows a portrait of the admiral Andrea Doria, an outstanding representative of one of the Strada Nuova families. All the iconographic items in the image are used as links to questions that allow the player to increase his knowledge (also through trial and error) about Andrea Doria, Genoa, and his era. Portraits are common in art. for instance, a *ContextualizedQuestion* game may be used to analyze in depth a portrait of a woman, beginning with details such as fashion, customs, and the life of the noble women of those times.

While, for iconic images, such as those in Figure 8, *ContextualizedQuestions* allows delving into the static/symbolic aspects of an image, the same task typology may be useful for developing the narrative aspect of other types of pictures. For instance, Figure 9 depicts the rape of the Sabine women.

In *VisualQuiz*, the image analysis is simpler and quicker and takes place through comparison. If an image is richer in contents, it makes more sense that it is used in a *ContextualizedQuiz* in order to invite the player to build a network of knowledge by reflecting on that image.

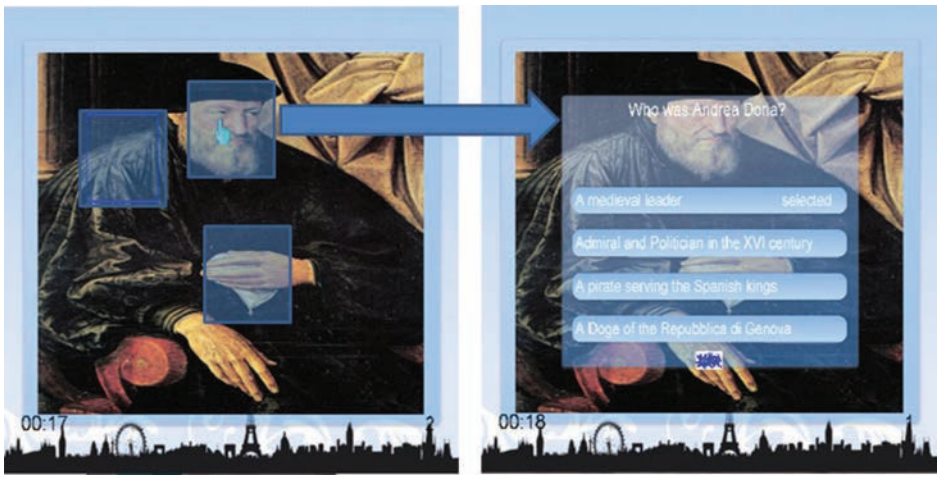

Fig. 8. Example of a Contextualized Question about Admiral Andrea Doria. By pressing on an active area, the player can access the relevant question.

Fig. 9. Luca Cambiaso. Rape of the Sabine Women (a sample of ContextualizedQuestions).

More generally, the *VisualQuiz* is best suited to provide limited basic information about a target object. The aim is not to explore it, but to recognize it (via comparison with different objects). The text in question should provide the key (e.g., the name or the function) that the player should immediately associate with the object. For instance, "Which of these is the San George palace?" (the player is shown a set of buildings). The text may also be a bit longer, providing more information about the place in question. This task is important for objects that a player should be able to recognize and associate with fundamental information as soon as possible. Thus, this task typology is particularly appropriate for players who are visiting a city for the first time. In the automatic task-scheduling system (the EE), the task should have a high value in the *popularity* metadata, indicating that it is appropriate for an initial visit to the city.

Figure 10 shows a simple example where the player has to recognize the most famous palace (probably) on Strada Nuova. *VisualQuiz* also offers the possibility of verifying thematic tourist routes. For instance, the player may be presented with a set of portals (or other architectural elements) that he may (or may not) have encountered while walking through Strada Nuova.

For *Quiz* and *VisualQuiz*, the choice of possible answers is important, so that the user can reason among possible alternatives. Along with the "find the right answer among N," its negative complement

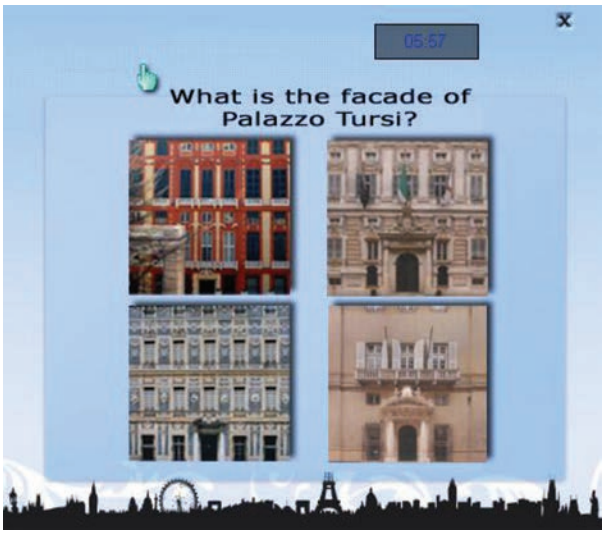

Fig. 10. Sample of *VisualQuiz*.

"find the wrong answer" allows the player to think about a larger number of correct "properties" for the target object.

WrongDetails and *MissingDetails* call the user's attention to details that have been changed in the picture. In order to answer the quiz, the player should usually be placed in front of the 3D representation of the object, so that he or she can compare the modified image with the actual virtual reality model. This can be done by the game author by assigning the minigame to the relevant PoI. In modifying the image, the author should consider the most relevant aspects, such as symmetry, colors, and structural elements in a façade, or relevant symbolic details in a picture (that could be clearly explained in the conclusion and possibly in the introduction). The objective is that the player should investigate and reason about the image, and avoid a trial and error approach; this is taken into account in the score, which penalizes the number of wrong attempts (time and accuracy assessment can be balanced as presented in Section 5.2 "Task parametrization").

The main aim of *RightPlace* is to allow the player to build an easy-to-remember visual representation of a topic. The added value of this task typology is its support for mental map construction, which is particularly important for space-related concepts. For instance, the player could be asked to drag objects (e.g., cloth, oil, spices) and drop them on the right position over the Mediterranean map from which they were imported, or to put the palace names on the correct positions on the Strada Nuova map (Figure 11). Other RightPlace examples could be the positioning of thumbnails of pictures over the Palazzo Bianco gallery's map or of furniture over a 17-century flat, providing clues about the daily life of that time.

Unlike other image games, *Puzzle* relies completely on the plain content. The player moves pieces of the image in order to make its content appear when the puzzle is complete (according to the *gestalt*, the fully semantic perception of the content happens when the content is complete [Hothersall 2003]). Thus, the *Puzzle*'s cognitive efficacy consists in its focus on content. Consequently, this task is most effective when we want the player to experience an artwork. The title, author, and exhibition place may be the only introductory information, so the player would then work only on the content, without being distracted by details. The Ecce Homo by Caravaggio (Figure 12) is a perfect example of this. Of

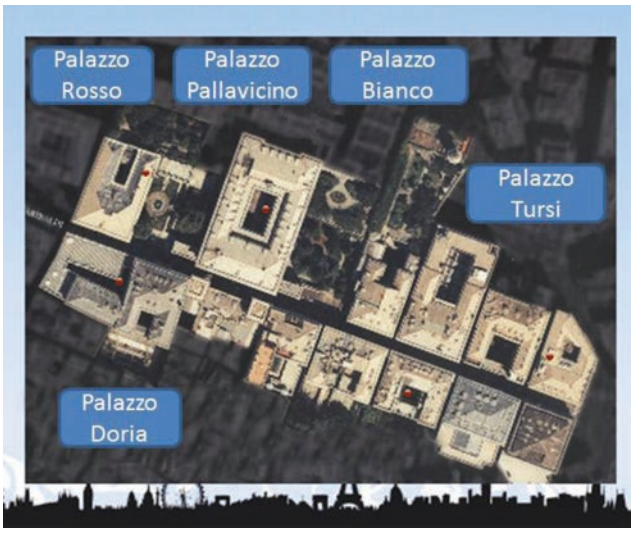

Fig. 11. *RightPlace* example: positioning palace names on their correct positions on the map.

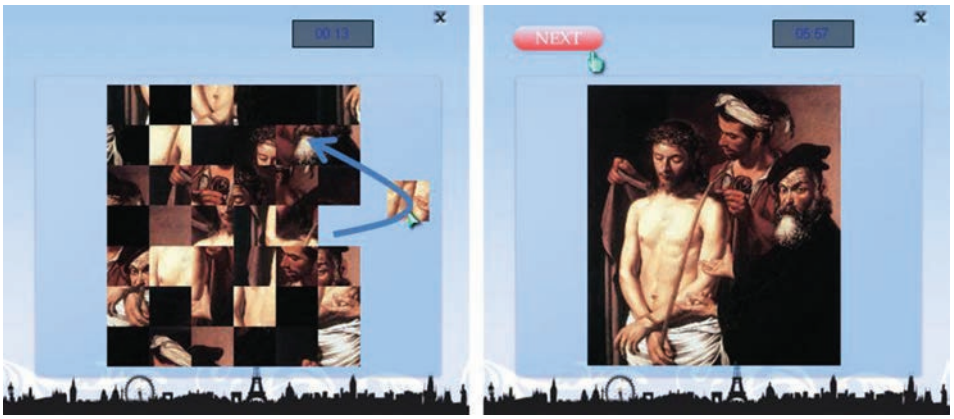

Fig. 12. Ecce Homo as a Puzzle game.

course, the same picture may be used for different types of tasks as well, but with different cognitive targets.

The *Couple* game relies on matching different thumbnail figures (or very short texts). This is similar to *RightPlace*, but simpler, due to the absence of contextualization on a geographic/historical/mental map. The author has to propose two homogeneous categories (placed in two different columns), and the player has to understand them and identify the differences among their representatives, so to be able to find the matches. This typology may be applied to several cases, such as picture-author, picture-name (Figure 13) or picture-picture (this may be a bit more complex, the matching criterion could be the same author or the same period/school).

The CatchIt! and *CulturalTetris* are arcade game typologies, where the focus is on action and the player is stimulated to react promptly. *CatchIt!* has a narrative structure, introducing a background (could be a picture of ancient times, with a prominent place, e.g., a tower, balcony, for launching objects)

Fig. 13. *Couple game* example: associate names with pictures.

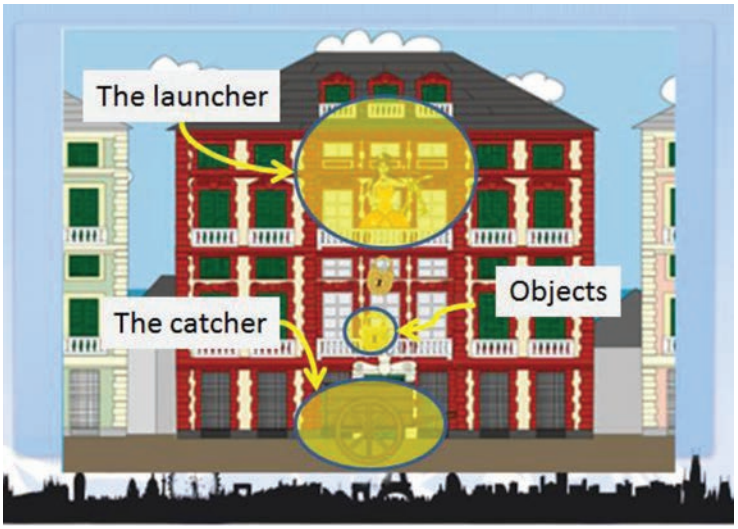

Fig. 14. *CatchIt!* example: catching the right objects and avoiding the others.

and two characters, the launcher and the catcher. The player, controlling the catcher, has to collect the "right" objects and avoid the others. This makes it suited to facilitate memorization (e.g., of historical facts). For instance, Figure 14 shows a game built on the historical fact that the Duchess of Galliera gave the keys of her palace as a grant to the city of Genoa. Other possible implementations may involve launching food ingredients, where the catcher may only take those that are used for local recipes.

Table IV is a summary of the main features of the game typologies.

9. USER TESTS

In this section we discuss the results of a user lab test we performed in order to assess the effectiveness of minigames for learning. In particular, the idea was to allow a CH expert to qualitatively and

Table IV. Features of Game Typologies

	Manuscr	Image Compr	Context Question	Quiz/ VisQuiz	Wrong/ MissDet	Right Place	Puzzle	Couples
Playable on one image		X	X		X		X	
Playable on several imgs				X		X		X
With questions		X	X	X				X
Playable on a text	X						X	
Focus on details		X	X	X	X	X		
Focus on overall content	X			X		X	X	X
Build a concept map			X	X		X		
More-in-depth info	X	X			X	X		X
Comparison to distinguish objects								X
Comparison to contextualize objects				X		X		
Focus on links from overall content		X		X				
Focus on links from details			X					
Consider the matching				X		X		X

quantitatively compare the performance achieved by playing minigames with reading an equivalent document featuring images and text.

The target of the experiment was to verify domain knowledge acquisition by nonexperts, in particular by exploiting as an example the activity of Luca Cambiaso, a 16th century Genoese painter. The content for the minigames was intended to give players a concrete idea of Cambiaso's artistic production, by inviting them to directly investigate the images in detail. In particular, the chosen themes privilege the frescoes and highlight the evolution of Cambiaso's work, from a rich and precious chromatic painting to the expressive rigor of his late work. The learner had to confront the images directly, with only a minimum addition of written text, with the goal of stimulating visual education and improving analysis and the capacity for reflection. The aim of the game, in fact, is to promote the history of art, which is essentially a history of images. And gaming, given its typically nontextual nature, is expected to be particularly suited to this purpose.

9.1 Procedure and Results

As test users we recruited nine MSc and PhD students in Information and Communication Technologies Engineering at the University of Genoa. None of them were familiar with Luca Cambiaso. They reported having a good level of familiarity with computers (4.4, in a 1-5 Lickert scale); videogames (3.6); and low familiarity with CH content (1.7). One was a female (11%); 8 males (89%). Apart from this last imbalance, this was a significant target population, in particular if we consider SGs as a tool for increasing learning opportunities for people not directly interested in the educational topic in question.

The work on Cambiaso was divided into four areas (paintings, frescoes, drawings, and biography) and made up the content of the tests. For each of these topics, our CH expert prepared one minigame (the typologies were ContextualizedQuestion, ImageComprehansion, and Manuscript, as they seemed the most appropriate for image analysis and the study of additional information about a painter) and one paper form containing the same visual and textual information (introductory and concluding texts). The paper form also contained some additional text to match other information in the minigames (in particular, from questions and answers). All the texts were written to be interesting and pleasant to read.

Every player was asked to design three games and read three paper forms, one for each of the topics. The order and assignment of tasks was varied so that all minigames and forms were used in a balanced way. Players were asked to do these assignments in their free time, and hence their behavior was quite unconstrained. At the end of the test (total time of around 25 minutes), every player was asked to respond to a questionnaire with five questions for every topic, for a total of 30 questions (20 closed, each one with 4 possible answers, and 10 open).

For every topic, each test user's knowledge acquisition assessment was expressed as a real number ranging from 0 to 1, which was obtained by averaging the score of each question. In the multiple answer case, a value of 1 was assigned for correct answers, 0 for wrong answers, while a 0-1 real number scale was used by the CH expert to assess the users' open answers. The final average score was 0.85 (std dev: 0.06) for the minigame treatment, and 0.74 (std dev: 0.12) for the illustrated texts. The difference is not statistically significant according to a one-way ANOVA test $F(1, 52)$, $p = 0.25$.

We also asked users to rate their experience in terms of pleasure, with an average result of 3.56 (in a 1-5 Lickert scale). The usefulness of the games for learning was assessed slightly higher (3.84). Also relying on users' free comments, we attribute this difference to the fact that the minigame implementations were not yet fully satisfactory in terms of enjoyment, especially when compared to state-of-the-art pure entertainment games of similar types.

Finally, we asked users to assess (in a 1-5 Lickert scale) their willingness to redo the activity with minigames and with texts. The average score was 3.4 for games and 2.7 for texts. The difference is slight and not statistically significant, according to a one-way ANOVA test $F(1, 16)$, $p = 0.10$.

9.2 Observations and Comments

The CH expert who had prepared the content observed the test users' activities (also in other informal tests with more minigames) and corrected the final questionnaire. She made several comments, which we report in the following, as we consider them useful in understanding the added value of the minigames and where and why they are useful.

From the multiple-answer questionnaire, it emerged that learners respond better to questions related to the image iconography (e.g., details, meanings, symbols), while they had greater difficulty in analyzing the painter's artistic language (i.e., the artist's graphic and pictorial characteristics). For instance, most learners failed to answer the question about what painting belonged to the painter's final phase. This answer would not require knowledge of Cambiaso's chronology, but would require reasoning about the subject and his use of color, combined with a hint provided in the short introductory text.

We feel that players were not confident that this question could be answered without previous knowledge (i.e., only by exploiting their experience during the game), and thus that they could actually learn complex concepts from the game, provided that they engaged in the activity in-depth and also reasoned about possible connections among the concepts, which they have to discover. Learning concepts through games requires an investigative attitude, which games should and can stimulate and reward (e.g., through score competition and other feedback), but is not automatic. Thus, we have learned that players should be made aware that they can solve complex quizzes if they pay attention to and reason about their entire game activity, including the relationships among the game contents and the brief introductory and concluding texts. Also, that we should design more comprehensive tests, with overall score competition on a wider test-player basis, longer playing times, and allowing replay, so that players can practice more if they like the activity.

From the open answer questions, we first noticed that the number of responses was quite small. Answering the questionnaire probably required too much effort. But this also shows that our tests took place in realistic settings, in particular in terms of user freedom. From the responses, we can see that

test users who had read the document instead of playing the games tended to respond by reporting only one (important) argument (probably the one that most affected them during their (relatively) shallow reading), while users who had played the games responded in a more complete way. Thus, it seems that playing games leads to obtaining a wider vision.

In general, we argue that playing minigames helps us acquire knowledge about the iconography of an image and the subjects represented by it, but is not enough to gain knowledge about the painter's technique and artistic language, which are upper-level concepts, and hence require more reasoning and reflection, in particular for people who are not art history experts. More specifically, a game (in particular the *ImageComprehension* and *ContextualizedQuestion* typologies) raises a player's interest in some features (typically the iconography), which would probably have been neglected otherwise. In this sense, the game can be seen as a sort of guided analysis of an image. Compared to reading text, a game forces the player to focus on questions more strongly, and thus promotes a more focused study of the image. Such question-based learning requires more effort, which favors knowledge acquisition and retention, but users also seem to enjoy it, especially if the gaming context is appealing.

Considering the minigame typologies, we see that *ImageComprehension* drives the players' attention to the details of an image. But, by themselves, games are not able to overcome the players' lack of familiarity with image analysis and their poor visual education. For these upper-level skills, it seems that the minigame typologies we have developed can be used as test and practice tools, but a previous, more complex, educational phase must also be undertaken. In addition, it is fundamental that the text and image complement each other. A typology like *VisualQuiz*, which almost exclusively relies on the image medium for gathering data, seems weak. In general, we also observed that players prefer very simple user interaction modalities, otherwise they tend to lose concentration, which, consequently, lowers the effectiveness of the game. In particular, we observed that drag and drop is a critical operation, in particular for the *RightPlace* and *Couple* games.

The user tests suggested possible improvements on the implementation of some games. For instance, at present, *ImageComprehension* is simply a multiple-answer quiz, with the related image alongside. But interactivity could be exploited better, for instance by making it possible to enlarge the image, particularly when the player cannot answer immediately (maybe with a penalty score, or by exploiting other typical game features). The game should also allow a comparison with previously explored images, for instance, made available via a virtual knapsack. We believe that allowing a link with previous experiences would enhance the educational effectiveness of the game. Improvements should also concern user feedback. For instance, in case of a wrong answer, a minigame should not stop, but provide feedback to support further reasoning until the player answers correctly.

We also asked users whether they perceived a split between the 3D settings and the 2D minigames. They generally reported that as long as the tasks are meaningfully integrated in the adventure (i.e., that they serve the game's final goal), no disruption is felt. In the specific case of the treasure hunt game, this makes the 2D minigames necessary for achieving the goal: a path that allows exploration and discovery.

10. CONCLUSIONS AND FUTURE WORK

The spread of virtual environments and related technologies is likely to offer new modalities of knowledge acquisition and interaction with virtual representations of CH. This makes it possible to create compelling adventures set in the context of faithfully reconstructed places of artistic interest, where the player can have a information-rich, contextualized experience. The entire experience should be perceived as a compelling, exciting, and culturally meaningful story in which the player can become familiar with items in the territory. Here, it is important to highlight that by embedding tasks and minigames in a 3D exploration of the world, we can realize something like the "digital analogy" of a

real visit to a city/region, which is typically enhanced by visits to museums, galleries, churches, important buildings, and other memorable places. This is the traditional way that a number of people—from tourists to scholars—have raised their spirits by appreciating foreign artifacts, habits, and people, and by developing knowledge about history, art, and geography.

Discovering and appreciating CH has a lot to do with education and learning. SGs represent a significant opportunity for learning, and should serve to embed high-quality, contextualized information so that players can get the most from their exploration of the virtual environment. This requires defining new methodologies and tools for effective production. To this end, we have abstracted a conceptual framework relying on a generalization of the task-based learning theory. The model defines games set in realistic VWs enriched with embedded educational tasks. The model involves pedagogical task annotation, which allows decoupling the tasks (they can be reused in different SGs) from the definition of their delivery strategy in a specific SG. Games implemented with this model are not competitive with an ad-hoc-designed SG, for instance one targeting a specific historical topic. However, this idea meets the emerging requirement for games that are developed efficiently by CH experts and teachers, and also exploits the growing availability of 3D models. For instance, for the user tests in Section 9, a CH expert prepared 45 minigames (we used only six of them due to time constraints in the formal tests) in eight days, simply reading short instructions and holding brief conversations with the TiE designers.

The tests, aimed at verifying knowledge acquisition on CH topics in a pleasurable and engaging way, have shown that games are appropriate for supporting the study of images, in particular iconography. Compared to reading text, a game more strongly forces the player to focus on problems; this favors knowledge acquisition and retention. Learning nonimmediate concepts requires an investigative attitude, which can be encouraged by well-designed games. Good design involves usability, graphic appeal, appropriate content, and connections that a player has to discover among the contents. Players should be asked to pay attention to and reason about their whole game activity, including the relationships among the game contents and the brief introductory and concluding texts. More comprehensive tests are needed to better investigate educational effectiveness; however, the first results are promising, especially in terms of user motivation and the creation of new opportunities for learning about CH. This is a key target for SGs, which aims at extending learning opportunities, particularly in attracting a demographic that is traditionally averse to pursuing cultural activities. The support by SGs for learning CH is a new challenge that is worth investigating further. The main potential of a game is to stimulate engagement and a reflection-based investigative attitude, which matches the treasure-hunt structure well. But the minigames and the structure itself have to be improved in order to better support procedural reasoning.

The proposed approach simplifies authoring work that is supported by a visual authoring tool. According to the TiE project partners who have used it, the toolkit's structure allows organizing material clearly, thanks to the exploitation of the PoIs as points of reference in the resource space. This way of collecting and structuring material around clearly defined and simple focus points is similar to the mind maps concept, and thus can be applied to different applications areas besides CH, as well. It is considered to have an important educational value, since it encourages students to study material and organize it in a useful way.

Based on our experience, we have studied how to exploit the interactive features of an SBSG to support promotion of CH. Generally speaking, all the tasks typologies are potentially valid for any topic. The criterion for choosing a task typology is related to the expected cognitive target the author wants to propose. Every typology is a different means of representing knowledge; hence the authorial role is fundamental in representing (transmitting) knowledge. We have also tried to show the potential of the implemented task typologies and how they fit different types of CH educational needs and perspectives through a set of real-world examples.

The experience, tools and methodology presented in this article open up further research questions and perspectives. First, we need more extensive user testing in order to assess and analyze the support of the proposed framework for effective learning in an entertainment context. Second, user adaptivity (e.g., in terms of difficulty, learning styles, human-computer interaction, etc.) should be studied more extensively and enhanced. Third, the emergence of living worlds populated by non-player characters (NPCs) equipped with atificial intelligence capabilities and characterized by proper psychological features and cultural behaviors has opened new and challenging perspectives. In particular, it would be interesting to explore new task typologies that rely on interactions between the player avatars, the NPCs, and the 3D environment.

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