A Model for the Design of Puzzle-based Games Including Virtual and Physical Objects

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A Model for the Design of Puzzle-based Games Including Virtual and Physical Objects

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ABSTRACT

Multiple evidences in the Technology-Enhanced Learning domain indicate that Game-Based Learning can lead to positive effects in students' performance and motivation. Educational games can be completely virtual or can combine the use of physical objects or spaces in the real world. However, the potential effectiveness of these approaches largely depends on the pedagogical design behind the game and to what extent this design is aligned with the requirements of specific educational situations. This paper focuses on puzzle-based games, as a particular strategy that can foster students' problem solving, analytical and memory skills, and on the role of teachers as designers of meaningful games. The paper presents a model (conceptual model and XML binding) to represent puzzle-based games including virtual and physical elements. The expressiveness of the model is shown with several cases to illustrate that the model covers a wide range of significant puzzle-based games. The results from an exploratory user study show that, except two elements of the model that require revision, teachers understand the model and can apply it to solve design tasks.

Keywords

Game-based learning, Puzzle games, Game design, Conceptual model, Information model, Exploratory study

Introduction

Educational games are being backed up in the Technology-Enhanced Learning domain as strategies that can lead to worthy learning outcomes. These games emerge as an option to address the learning and motivation requirements of the current generation of students (Prensky, 2001). Empirical evidences support the positive effects of computer games as learning tools. The evidences indicate that games implementing pedagogical designs can strengthen and support school achievement, cognitive abilities, motivation towards learning, reflection, attention and concentration (Jenkins, 2002; McFarlane et al., 2002; Bottino et al., 2007). Furthermore, the nature of educational games is very varied, from videogames to mainstream games (Mitchell & Savill-Smith, 2004). Also, the majority of educational games are completely virtual, allowing students to interact with virtual representations of concepts that are difficult to access in the real world (Melero et al., 2011). However, there are other relevant games that include the use of physical objects (with tangible interfaces or embedding sensing technologies) that address specific educational needs (e.g., manipulation of physical objects vs. symbolic representations, physical interaction for particular therapies, etc.) (Li et al., 2008). Moreover, other games are played in physical spaces considering real objects and their locations to facilitate contextualized learning (Avouris & Yiannoutsou, 2012).

Despite the potential benefits of educational games, teachers do not broadly adopt them in formal learning settings (Williamson, 2009). The reasons behind the low adoption include that the available games do not often fulfill the requirements of particular educational situations, and that teachers do not have advanced technological skills to create or adapt their own educational games (Melero et al., 2011; Tornero et al., 2010; Yang, 2005). Diverse research efforts are being devoted to provide easy-to-use game editors, such as <e-Adventure> (Torrente et al., 2010), Alice (Conway et al., 2000), Squeak (Ingalls et al., 1997), and GameMaker (Overmars, 2004). These authoring tools have been developed to allow teachers to design educational games. Unfortunately, these tools can be still too complex for some instructors (Tornero et al., 2010), hard to adapt to individual courses and require much time for development (Yang, 2005; Tornero et al., 2010).

This paper focuses on puzzle-based games as a particular educational strategy to feasibly involve teachers as designers of the games. The nature and duration of this type of games is typically equivalent to other types of learning tasks for the classroom or field trips activities (Michalewicz & Michalewicz, 2008; Falkner et al., 2010). Indeed, the proposed games could be used in laboratory sessions, as a complement to traditional approaches. But also, students could play these games as a homework assignment to reinforce the concepts learned in classroom.

Besides, teachers can use puzzle-based games to engage their students in the subject topics, while at the same time foster students' problem solving, analytical and memory skills (Huang et al., 2007; Bottino et al., 2007). Puzzle games have simple rules around the basis of a challenge that requires interrelating pieces over a given board (Huang et al., 2007). Their rules can be defined independently from content and clues (Crawford, 1982) and, therefore, they can be applied to multiple subject matters. Besides, the concept of puzzle games is not tied to a specific platform or type of technology. Indeed, current advances in technologies and the generic characteristics of puzzle-based games enable the consideration of virtual and physical objects in the design of the puzzle game (as pieces or slots).

Therefore, this paper proposes a model to support the design and computational representation of puzzle-based games including virtual and physical objects. The main aim is to enable teachers the design of this type of games. First, we discuss relevant aspects around the design of puzzle-based games, followed by the proposed conceptual model, and its XML binding. Second, we illustrate how the model covers a variety of significant puzzle-based games including virtual and physical objects. Third, an exploratory user study is presented to analyze the extent to which teachers understand and are able to use the model to complete game-design tasks. Finally, we discuss the main conclusions to highlight the contributions of the paper.

Design of puzzle-based games for education

Several studies have identified different factors to consider when designing educational games (Fisch, 2005; Kirriemuir & McFarlane, 2004; Sandford & Williamson, 2005; Squire & Jenkins, 2003). The factors suggest that games should be based on constructivist learning theories, promote active learning and metacognition; clearly define the learning goals and tasks, be challenging and progressively increase the level of difficulty; provide immediate feedback and task-related supportive learning; and, offer help and hint structures to scaffold players along the game flow (Hjert-Bernardi et al., 2012). In this context, scaffolding refers to support mechanisms (e.g., hints or supportive learning material) that thoroughly guide students towards the successful completion of the learning activities proposed in the game (Wood et al., 1976).

Concerning game design models and frameworks, a broadly recognized useful approach is the 4-dimension framework proposed by de Freitas & Oliver (2006). This framework aims at helping teachers to evaluate the potential of using games- and simulation-based learning (Figure 1). We adopt this framework to analyse and extract the main characteristics to consider when supporting teachers in the design of puzzle-based games.

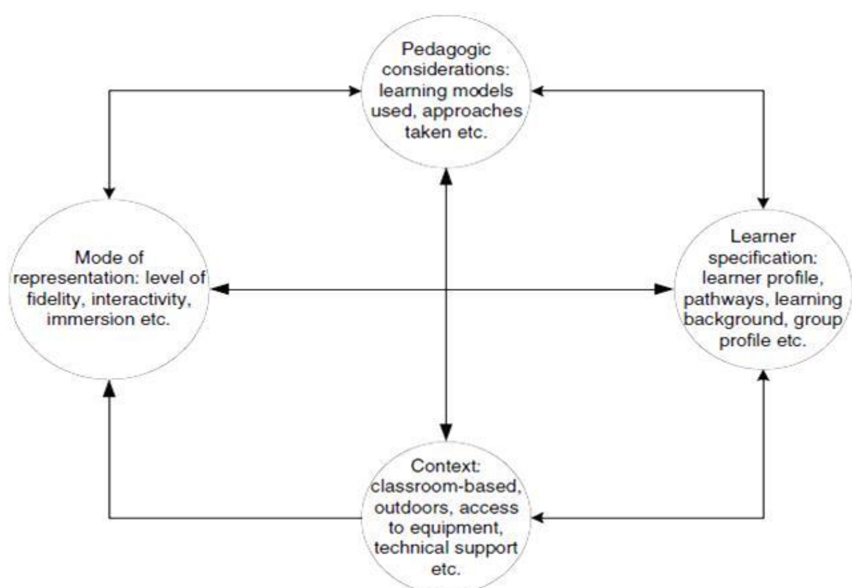

Figure 1. Framework for evaluation educational games (de Freitas & Oliver, 2006)

The first dimension of this framework focuses upon the particular context where play/learning takes place. In that sense, mobile technologies make possible to extend the learning environment far beyond classroom walls and school schedules (Liu, 2007). Also, mobile learning enhances traditional educational methodologies with greater portability and flexibility (Chang & Sheu, 2002). That means mobile games provide a way for learning activities that requires physical motion, problem solving, inquiry and collaboration (Spikol & Milrad, 2008; Avouris & Yiannoutsou, 2012). For this reason, it seems to make sense to consider mobile learning and games-based learning not as distinct experiences, but as experiences that could fruitfully be combined (Facer et al., 2004).

The second dimension focuses upon attributes of the particular learner or group. This may include the age and educational level, as well as specific components of how students learn including their learning background, styles and preferences.

The third dimension focuses upon the internal representational world of the game (i.e., the mode of presentation, the interactivity, the levels of immersion and fidelity used in the game). In this line, we differentiate between virtual and physical objects to represent both the different pieces and boards of a puzzle game. Interacting with virtual representations allow students to comprehend and manipulate abstract concepts that cannot be accessed in real world. Whilst there are learning situations in which physical representations have clear benefits: physical objects can be more easily understood than more symbolic ones, it is easier to demonstrate knowledge with physical actions, and solving problems with concrete objects can be easier than using symbolic representations (O'Malley & Stanton-Fraser, 2004; Li et al., 2008).

The fourth dimension promotes the practitioners' reflection upon methods, theories, models and frameworks used to support learning practice. Several models have been used to describe the activities' flow of educational games. One example is the Game Achievement Model (Amory & Seagram, 2003) that takes in consideration the learning objectives for the game and the storyline that encompasses these objectives and is defined as actions or activities. Also, Educational Modelling Languages have been studied for making digital games for learning purposes, and how aspects of gaming and learning have been combined with educational standards. In that sense, IMS Learning Design (Koper & Olivier, 2004), a specification for describing sequences of activities associated to user roles has been proposed as an option for designing educational games (Kelle et al., 2011).

We argue that the previously discussed design factors and dimensions can be used as the basis for a model that enables teachers to design their own puzzle-based games according to the educational needs. In particular, we focus on educational jigsaw puzzles. The objective of any jigsaw puzzle is the arrangement of a set of given pieces into a single, well-fitting structure that interrelates the pieces. Puzzle should be interesting because its result is not immediately intuitive; they can foster students' problem solving, analytical and memory skills (Huang et al., 2007). Besides, there are several reasons that make puzzle-based games interesting approaches to involve teachers as designers. Puzzles usually have simple game rules (simplicity); their rules can be defined independently from content and therefore they can be applied in a wide range of subject matters (generality, independence); and their nature and duration is typically equivalent to other types of learning activities for the classroom or field trips (Michalewicz & Michalewicz, 2008; Falkner, 2010).

A Model to design technology-supported puzzle-based educational games

Conceptual model

Aligned with the factors and characteristics of games and puzzle-based design discussed in the previous section, Figure 2 adapts the (de Freitas & Oliver, 2006) framework to describe an overview of our model. Overall, a design of a puzzle-based game contains a learning flow consisting, at least, of a gaming objective, and a story structured by levels (which may relate to difficulty degrees or other issues)..Different levels form the story of the game, and each level of the game presents either a single activity or a group of activities. Each activity includes a puzzle, and players have associated specific activities depending on their role within the game. Also, the context is a factor to consider in the design of the game since it can be done indoors or outdoors, allowing situated experiences. Each puzzle is represented solely by pieces, but also could be based on a board with slots where to place the different pieces. This means, puzzles could be solved on the one hand, by relating pieces among them; or, on the other hand, by relating pieces with the corresponding slots of a board. Both pieces and slots can represent virtual objects or computer-recognized physical objects.

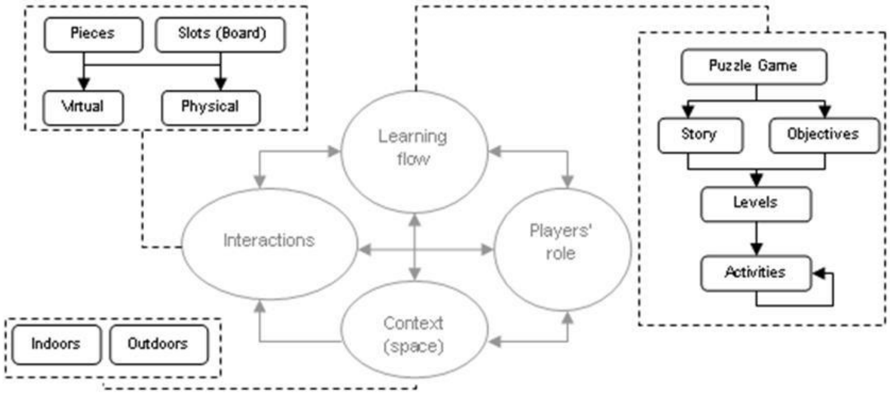

Figure 2. Overview of puzzle-based game design including virtual and physical objects

The entities depicted in Figure 2 can be conceptualized in a set of elements and their relationships. Figure 3 represents the different relationships that can be established between the different conceptual elements of our proposed model for puzzle game design. The story of the game specifies which role has to perform which activity and at what moment in the gaming process. For a player role, outcomes are stated as gaming objectives. These outcomes are achieved by performing learning activities, within the levels of the game, with the help of hints that scaffold the learning process if needed. In order to solve the learning activities, a set of (virtual or physical) pieces is provided to the players to propose their own solutions. Pieces and their relations could provide mechanisms, such as hints, questions or supportive learning material, to scaffold the gaming process as well. Besides, pieces could be part of a board in which players should relate each piece with its corresponding slot. Otherwise, players should relate pieces between them to propose the solutions. Depending on the puzzle game design (e.g., a virtual puzzle game, a puzzle game for a museum, a puzzle game designed to be played in a city), either pieces or slots could have associated virtual, tagged or geo-located positions.

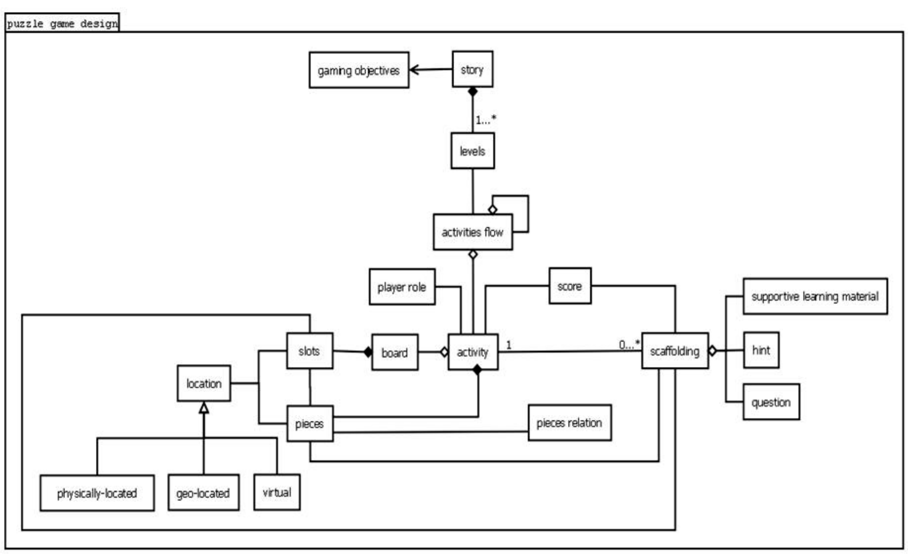

Figure 3. Conceptual model of puzzle-based game design

Information model

The conceptual model previously explained can be computationally represented by an XML binding as shown in Figure 4. More specifically, the computational representation for a puzzle game design includes:

- The title for a puzzle game design as well as the game objectives.
- The story of the game that contains the levels to be carried out sequentially.
- Each level defines who has to perform which activity or set of activities. That means, levels link each player-role to a specific activity or activity flow (i.e., group of activities).
- Activities appear as single activities or they could be grouped in an activities flow. The activity provides a description about the problem that has to be solved by a player performing a concrete role. An activity also contains a reference to a metadata that defines the puzzle intended to solve the proposed problem. Each activity also can provide different scaffolding mechanisms to assist the player during the game as well.
- Puzzles are used when a player performs a concrete activity, but they do not form part of the activity description itself. Thus, each puzzle is linked to each activity of the game.
- Scaffolding is used by player roles when asking for some type of help while performing an activity. Scaffolding does not form part of the activity description itself neither.

```
puzzle-game-design
        title
        gaming-objectives
        story
                levels
                        level
                                player-role-ref
                                activities-ref
        components
                player-roles
                        player-role
                activities
                        activity
                                scaffolding-ref
                                puzzle-ref
                        activity-flow
                                learning-activity-refs
                puzzles
                        puzzle
                                metadata
                scaffoldings
                        scaffolding
                                metadata
        metadata
```

Figure 4. The main elements of a puzzle game design

The different puzzles associated to each activity are also defined by its corresponding XML document in order to be computationally represented as well (Figure 5).

```
puzzle
        rels-between-pieces
                piece
                        name
                        type
                        location
                        scaffolding-ref
                rel-between-pieces
                        piece-id-ref
                        feedback
                        score
        rels-pieces-slots
                board
                piece
                        name
                        type
                        location
                        scaffolding-ref
                slot
                        type
                        information
                        location
                        scaffolding-ref
                rel-piece-slot
                        piece-id-ref
                        slot-id-ref
                        feedback
                        score
```

Figure 5. The main elements of a single puzzle associated to an activity

- We differentiate two types of relations within a puzzle. First, those relations in which the puzzle is not contained into a board. They define only the relations that can be made between the different pieces that form the puzzle (rels-between-pieces). Second, the relations that has to be defined for relating the different puzzle pieces with the slots of the board in which the puzzle is contained (rels-pieces-slot).
- A piece includes its name, the type of piece depending on its representation (i.e., virtual or physical), and scaffolding mechanisms (i.e., hint, question prompt, or supportive learning material).
- A slot is defined by its type depending on its representation (i.e., virtual or physical), information to describe the slot, location (defined by coordinates {x, y, z} for virtual representations; or a geo-located coordinate, for in situ interactions), and scaffolding mechanisms (i.e., hint, question prompt, or supportive learning material).
- Each relation, for puzzles that only consider the relations between pieces (rel-between-pieces), is defined by the reference of the different pieces forming the specific relation, a feedback provided to the player depending on whether the relation is correct or not, and a score consisting on positive (correct relationships) or negative (incorrect relationships) points.
- Each relation, for puzzles that consider the pieces and the slots of a board (rel-pieces-slot), is defined by a reference of the piece and the slot forming the relation itself, a feedback provided to the player in order to inform whether the relation is correct or not, and a score consisting in positive points for correct relations, and negative points for incorrect ones.

Implementation guidelines and authoring tool prototype

The implementation guidelines introduced in this section should be understood as a possible approach suggested for the actual enactment of puzzle-based games. It aims to help game developers with the system design process.

A first authoring tool (Figure 6) has been created to generate the XMLs compliant with the information model for designing puzzle games. The tool is implemented as a wizard. First, the teacher specifies the title of the puzzle and the learning goals expected to be achieved by playing the game. Next, the teacher introduces the information associated to the levels for the game. For each level, at least, an activity with its associated puzzle has to be defined. In order to create the puzzle, the teacher selects between creating a puzzle of “relation between pieces” or “relation between pieces and slots”. Depending on this selection, the teacher specifies the demanding information, for instance, the content for the different pieces, slots, hints and the relationships between them. At the end, the different XML documents are automatically generated by the authoring tool.

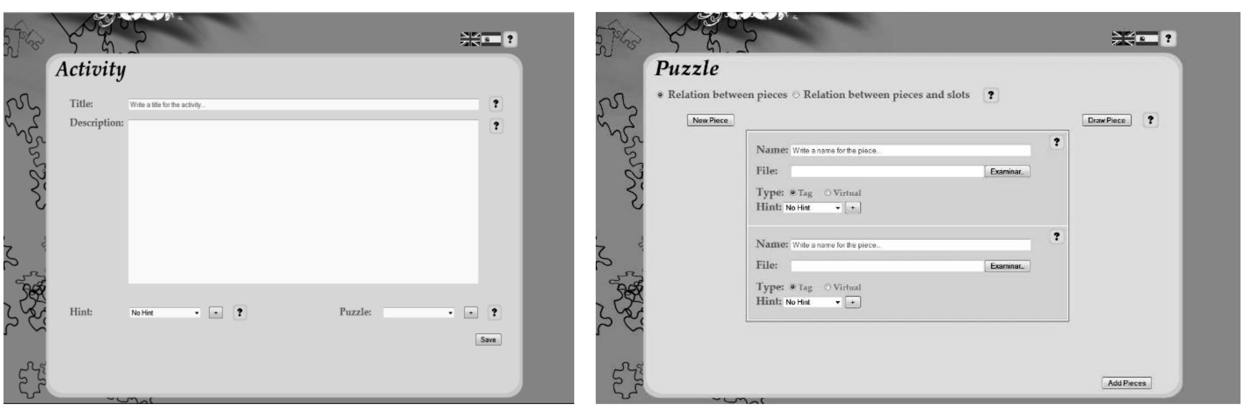

Figure 6. Some screenshots of the authoring tool

The XML format allows storing the data independently from specific platforms. Depending on the targeted platform, it is needed, an engine able of interpreting (parsing and instantiating) these packages of information compliant with the puzzle-based game model, and a player to execute the live interpretation of the game. Platform-specific engines (e.g., for handheld devices, tangible interfaces…) should read the information contained in the different XML documents and check the different constrains (e.g., to show the activities associated to a player role, to show the puzzle associated to a concrete activity, etc.). Therefore, platform-specific engines need to contain the business logic of the conceptual model for technology-supported puzzle games. The responsible of visualizing and dealing with the content provided by the engine is the platform-specific player (Figure 7). External interfacing can be included in the architecture by providing gateways to other systems (as similarly achieved in (Santos et al., 09)).

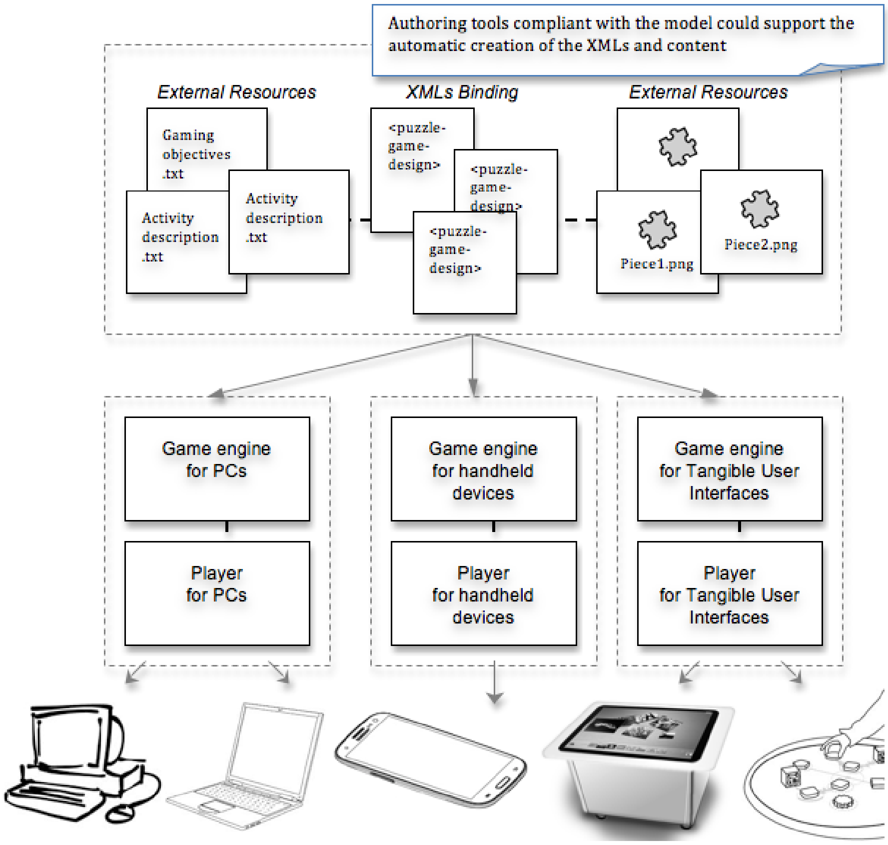

Figure 7. Schema of architectural components for enactment systems

Expressiveness of the model

To show the expressiveness of the model, this section discusses different examples covering a wide range of puzzle-based games. These examples include diverse virtual and physical objects' (as pieces or slots) combinations and are meaningful to different educational contexts. In concrete, several examples by the authors of the model, as well as third-party examples proposed by other researchers are described. Reporting not only authors' own examples, but also external ones, adds a stronger validation of the model expressiveness and shows how the model can be applied to a diverse variety of educational contexts.

Examples of puzzle game including virtual pieces and virtual slots

Several puzzle-based games, following a simplified version of the proposed conceptual model, have been developed. In concrete, the games aim at learning computer architecture, programming fundamentals, computing networks (Melero et al., 2012) and chemistry (Hjert-Bernardi et al., 2012). Examples of implemented puzzle pieces includes: logic gates (computer architecture), chucks of pseudo-codes (programming fundamentals), and elements of the periodic table (chemistry). All these games were designed and evaluated in laboratory sessions of different secondary and high schools.

The proposed conceptual model was also used by a secondary school teacher to conceptualize a game consisting in answering questions about different pictures of a contemporary art museum (Melero et al., 2013). This example shows a learning situation in which the implemented game was enacted in a field trip. The game content reflects concepts of different contemporary art pictures exhibited in the museum. Students, while visiting the museum had to answer different questions in situ using their smartphones. In order to implement the game compliant with the model: (a) each picture was virtually represented as a slot, the content of which was the question itself; (b) the possible options to answer a question were represented as virtual pieces; and (c) in order to indicate whether an option (i.e., piece) of a given question is correct or not, we used the “rel-piece-slot” element (see Figure 8).

Figure 8. Screenshots of the game and chunks of its corresponding XML representation compliant with the model

Example of a puzzle game including virtual pieces and physical slots

Lee and Chen (2008) propose a mathematical educational game for young children in an Augmented Reality environment to practice with the concept of addition and subtraction. This could be an example of a puzzle game in which virtual pieces and physical slots work together. The player has three dice (two numbered dice and one operator dice) that have to roll and calculate the outcome. Then, the player moves a piece on the board according to the outcome. The player who arrives at the finishing point first wins the game. The board is made of markers and pieces are augmented as 3D models. The players can select different boards and the 3D models player’s pieces would change as on the selected board. The representation of the game with the model would specify each board and its corresponding pieces as a different puzzle in the game. Each of the board’s markers would correspond to a physical slot, and the augmented pieces would be mapped as virtual pieces of the model. Thus, different “rel-piece-slot” elements would be defined to specify the possible relations that can be established between each piece and slot.

Example of a puzzle game including physical pieces and virtual slots

Two functional prototypes of puzzle-based games using physical pieces and virtual slots have been implemented (Ponz-Adán, 2012; Cardona-Serra, 2012) compliant with the conceptual model. These games reflect contents of computer architecture and programming fundamentals. Puzzle pieces were implemented using the ReacTIVision technology (Kaltenbrunner & Bencina, 2007), an open-source toolkit for developing tangible multi-touch surfaces. Particularly, the games consisted in matching the physical pieces, representing different computer science concepts, with their corresponding virtual slots (see Figure 9). Besides, both games were evaluated with secondary education students in different one-hour session of a laboratory class.

Figure 9. Screenshots of the game including physical pieces and virtual slots (Ponz-Adán, 2012)

Example of a puzzle game including physical pieces and physical slots

“The Smart Jigsaw Puzzle Assistant” (Bohn, 2004) is a computer application that operates with a physical jigsaw puzzle game that uses miniature RFID tags and a palm-sized RFID scanner to technologically support the interactions with both physical pieces and slots. The application is executed on a computer and monitors the current status of the physical jigsaw puzzle. Whenever the player chooses a new piece of the physical jigsaw game to be added to the previously combined pieces on the table, he or she scans it with a handy RFID reader connected to the computer. The application then automatically recognizes the added piece and updates the status of the jigsaw game on the computer screen. Both piece and slot elements would be specified as physical (setting the attribute type to “tag”) to comply with the conceptual model. The application would recognize the added physical piece and check, using the “rel-piece-slot” element, whether the piece has been placed in a correct position.

Exploratory study with teachers

In order to test whether teachers understand the elements of the model, we carried out an exploratory study in which they have to solve a proposed design task. Before discussing the results, we describe the proposed design tasks and the methodology applied in the study.

Methodology and design task

Teachers were recruited to participate upon an open invitation. Invitations were sent by email to two secondary education schools and one higher education (university) department. A total of 11 teachers replied positively to the invitation and agreed to participate in the user study. As done in (Derntl et al., 11), this study was organized as paper-based sessions. Participants used paper snippets representing the elements of the conceptual model to solve the design task. In particular, the sessions were structured as:

- Pre-test for gathering contextual information and the teachers’ background using technology or educational games in their learning approach (10 minutes).
- Introduction about game-based learning and the key elements of the model needed to build a puzzle game. Some examples using the elements of the model were shown as well (15 minutes).
- Paper-snippets introduction. Every participant received an envelope with paper snippets (see Figure 10), each representing one instance of an element of the conceptual model. Each paper snippet was divided into boxes that represent information about the element in conformance with the model. Besides, each element had its own unique colour in order to guide participants in placing connections between elements (5 minutes).
- Puzzle-based game design task. After the introduction, every participant had the task of representing one scenario (two narratives of puzzle-based game scenarios were defined and randomly offered to participants) (50 minutes). The resulting designs created with the snippets were collected, once the participants finished the design task.
- Post-task survey. Participants were asked to fill out a post-task survey, which aimed to collect additional information about what caused them more problems during the task (10 minutes).

Figure 10. Sample of snippets (i.e., piece, slot, relation between pieces, and relation between piece-slot)

As a task protocol, participants were not offered any help or guidance during the task other than (a) provision of a cheat sheet with a tabular overview of the elements of the conceptual model and (b) personal answers to questions for clarification.

Prototype solutions for each of the two proposed scenarios were created by decomposing the overall task into solution items. Each solution item consisted of an action that needed to be performed with an individual element of the model, or a small group of elements, in order to obtain a correct solution. Each solution proposed by the participants was individually analysed and matched with the prototype solution. Table 1 lists the scenarios and includes sample snippets. The complete collection of snippets composing the specification of the games described in the scenarios is available as an on-line appendix to this article (http://www.dtic.upf.edu/~jmelero/et&s/index.html).

Table 1. Scenarios proposed in the design task

Scenario
1. Imagine a non-native English student wants to improve his/her English vocabulary related to shopping. The first level aims at learning English words for different clothes [s1-1]. Each activity, in this level, consists in forming words of different type of clothes that are shown in pictures. The player, using different letters, has to construct the specific name of clothes shown in the picture [s1-2]. The next level consists in an activity for learning specific shop departments (dressing room, counter, etc.) [s1-3]. To this end, a map of the shop containing different empty spaces is presented to the player. Then, the player has a set of given words to place in a specific area of the map [s1-4]. The purpose is to match each word with its correct empty space in the map. During the game different hints can be provided to the player indicating for instance, the first letter of a word, the last letter, etc.
2. Using a Smartphone, a student has to find some contemporary pictures in a museum [s2-1]. The Smartphone shows, on one hand, the museum's map and, on the other hand, a set of pieces that represent specific parts of concrete pictures [s2-2]. The museum's map also contains different highlighted locations that correspond to specific pictures in the museum. Students have to match each piece with its corresponding picture/location. Each picture in the museum has associated a physical card (e.g., NFC tags, QR-Code, etc.) [s2-3]. The player has to read the physical card to indicate that he/she has reached a specific location. Then, once the player arrives to a concrete location and read the physical card, he/she can select which of the virtual piece correspond to the concrete the picture [s2-4]. Each virtual piece may contain some hints indicating the area of the museum where the student can find the related picture.

To analyze to what extent teachers were able to complete the specification of the games and identify the missed elements of the resulting designs, we use a chart taking into account the aforementioned decomposition of the overall tasks into solution items. Thus, Table 2 summarizes the different data sources considered in the evaluation.

Table 2. Data sources for the evaluation

Data source	Type of data	Labels
Pre-test	Quantitative ratings and qualitative opinions by the different participants.	[Pretest-all] [Pretest-X] Where X is the number of the user, from 1 to 11
Participants Solutions	Proposed solutions by the different participants using the snippets	[Sol-ScX-Y] Where X is the number of the scenario (1 or 2) Where Y is the number of the user, from 1 to 11

Post-test	Quantitative ratings and qualitative opinions by the different participants.	[Postest-all] [Postest-X] Where X is the number of the user, from 1 to 11
Observations	Record of direct observations during the experience by 2 researchers.	[Observer1] [Observer2]

Results: Teachers' profiles, opinions and previous experiences with educational games

Participants' average teaching experience is 5 years, in different subject areas. Half of them have a technical background. 75% of teachers teach in secondary education; the rest teaches in higher education. All the participants use technology in their classes, with YouTube (63%), Moodle (45%) and Facebook (36%) the most used tools. All participants rated with 4 or more (in a scale from 1 to 6) the need of using technology in education to enrich the students' learning experiences.

Using a scale from 1 to 6, 70% of the teachers rated with 4 or more the interest of using games in education. Also, 80% of the teachers rated with 4 or more the usefulness of games in education. In this regard, some comments were: "Educational games can be a complement to the students' learning in other to motivate them" [Pretest-2], "Learning by means of games stimulates and motivates students, but designing appropriate games can be difficult for a teacher" [Pretest-5]. These data indicate that teachers perceive educational games as important approaches to support their lessons because technology and gaming motivate students. However, the teachers also recognize that its design is time consuming and they do not have enough resources to easily create their own games. It seems that for this reason teachers tend to adopt mainstream games in their lessons.

Half of participants had adopted or made some variations from existing games. These games were "collaborative games, avoiding competitiveness, intended to work on retention capacity and strategy" [Pretest-2], "games such as memories or scatergories" [Pretest-4], and "games to form sentences using cards, to guess famous people" [Pretest-11]. The other half of participants do not use educational games because "the devoting time; I prioritize to explain my lessons" [Pretest-2], "There are not games covering the topics of my subject" [Pretest-8] and "I don't know the technology or the means to include games in my teaching" [Pretest-6].

Results: On the outputs from the design tasks

The resulting designs created by the teachers were compared to the solutions prototyped for each scenario. The different teachers' profiles did not seem to influence the results of the experiment since their outcomes and opinions were overall quite aligned. Then, the data was aggregately analyzed, and it was just indicated the teachers' profiles when appropriate. The comparisons are captured in Tables 3 (scenario 1) and 4 (scenario 2). Each table shows whether the participants used correctly the elements of the conceptual model for designing the puzzle-based games.

The percentage of conformity in the total sample for the results of the scenario 1 is 76%, whereby only 1 out of 4 solutions was rated at less than 50%. Despite final solutions, such as [Sol-Sc1-5], were simpler than expected; all participants were able to use and correctly relate the different elements of the conceptual model. Activities' flow was the more problematic element. In order to include several puzzles in a level, it is necessary to include the element activities flow that contains as many activities as puzzles are designed for the level (one activity per puzzle). However, [Sol-Sc1-2] specified the references of the different activities in the attribute "activity reference" (instead of using the activities flow element), [Sol-Sc1-4] specified for a single activity a group of puzzles instead of creating a puzzle per activity, and [Sol-Sc1-9] used the activities' flow snipped to directly relate the different puzzles for a level, instead of specifying the single activities included within the activities' flow and related each single activity to a puzzle. The percentage of conformity was also affected by the time devoted to design the proposed scenario; participants [Sol-Sc1-2] and [Sol-Sc1-4] (from secondary education schools) did not have enough time to finish their solutions. Two isolated mistakes referred to not using the puzzle-based game design snipped to indicate the title, objectives and levels of the games [Sol-Sc1-5]; and duplicate the same player role to different levels of the game [Sol-Sc1-9].

Table 3. Participants' solutions' conformity with the prototype solution of Scenario 1 (Notation according Table 2)

Scenario 1	Elements	Sol-Sc1-2	Sol-Sc1-4	Sol-Sc1-5	Sol-Sc1-8	Sol-Sc1-9
[s1-1]	Puzzle game design	✔	✔	✕	✔	✔
	Level	✔	✔	✔	✔	✔
	Player role	✔	✔	✔	✔	✕
[s1-2]	Activities flow	✕	✕	✔	✔	✕
	Activity	✔	✔	✔	✔	✕
	Puzzle	✔	✔	✔	✔	✔
	Piece	✔	✔	✔	✔	✔
	Rel. between pieces	✔	✔	✔	✔	✔
[s1-3]	Level	✕	✔	✔	✔	✔
	Activity	✕	✔	✔	✔	✔
[s1-4]	Puzzle	✕	✕	✔	✔	✔
	Board	✕	✕	✔	✔	✔
	Piece	✕	✕	✔	✔	✔
	Slot	✕	✕	✔	✔	✔
	Rel. piece-slot	✕	✕	✔	✔	✔
	Use of hints?	No	Yes	Yes	Yes	Yes
Conformity (%)		47%	60%	93%	100%	80%

The results for scenario 2 show that there is a generally high conformity of the teachers' solutions with the prototype solution. The percentage of conformity in the total sample is 85%. Despite final solutions were simpler than expected, all participants were able to properly use the different elements of the conceptual model. There was only an exception, [Sol-Sc2-6], in which the proposed solution was not satisfactory. The participant associated tag pieces for the pictures of the museum, and virtual pieces for showing chunks of some pictures of the museum. The expected solution was using a board with slots (i.e., QR-codes for pictures of the museum) and pieces (i.e., virtual pieces showing chunks of some pictures of the museum). For this reason, the solution was not considered correct since the participant did not use the expected elements. Besides, the attributes 'virtual' and 'tag', for the pieces (i.e., [Sol-Sc2-1], [Sol-Sc2-7], [Sol-Sc2-11]) and slots (i.e., [Sol-Sc2-3], [Sol-Sc2-6], [Sol-Sc2-7]), were not correctly used in some cases. A concrete error was the [Sol-Sc2-11] that specified both "relation between pieces" and "relation pieces – slots", when only "relation pieces –slots" was correct. However, this specific error seemed to be more related with the graphical design of the snipped than with the formulation of the model elements.

Table 4. Participants' solutions' conformity with the prototype solution of Scenario 2 (Notation according Table 2)

Scenario 2	Elements	Sol-Sc2-1	Sol-Sc2-3	Sol-Sc2-6	Sol-Sc2-7	Sol-Sc2-10	Sol-Sc2-11
[s2-1]	Puzzle game design	✔	✔	✔	✔	✔	✔
	Level	✔	✔	✔	✔	✔	✔
	Player role	✔	✔	✔	✔	✔	✔
[s2-2]	Activity	✔	✔	✔	✔	✔	✔
	Puzzle	✔	✔	✔	✔	✔	✕
	Piece	✕	✔	✔	✕	✔	✕
	Board	✔	✔	✕	✔	✔	✔
[s2-3]	Slot	✔	✕	✕	✕	✔	✔
[s2-4]	Rel. piece-slot	✔	✔	✔	✔	✔	✔
	Use of hints?	Yes	Yes	Yes	Yes	Yes	Yes
Conformity (%)		89%	89%	78%	78%	100%	78%

Results: On the design process

Participants encountered some difficulties in the design process in regards to: (a) the creation of groups of activities for designing different puzzles for a concrete level of a game, (b) referencing the different snippets, and (c) the design of the task protocol.

8 out of the 11 participants thought that they correctly understood the elements for the design of the game. However, participants have troubles with understanding some of the elements. The most problematic element was the activity flow [Postest-4-5-7-9-10-11]. In fact, as showed in the previous section, participants [Sol-Sc1-2], [Sol-Sc1-4] and

[Sol-Sc1-9] failed at creating activity flows. For instance, some participants indicated “I considered the activity about clothes as a one activity with various puzzles instead of an activity flow” [Sol-Sc1-5], and “I don’t distinguish between activity and activity flow” [Observer 1]. Other problematic elements were the pieces and slots [Postest-2-6-8]. In particular, some participants did not correctly understand the attributes ‘virtual’ and ‘tag’ for these two elements [Sol-Sc2-1-3-7]. These misunderstandings were mostly derived from the terminology: “I don’t understand the meaning of some concepts because they are unfamiliar” [Postest-1], “what is the difference between puzzle and board?” [Observer 1].

10 out of the 11 participants understood how to relate the different elements. Participants appreciated the examples showed in the introduction [Postest-4-8], and the use of different colours helps the participants to correctly design the games [Postest-1-5]: “The colors of the snippets were useful to design the game” [Observer 1]. However, the participants [Sol-Sc1-2], [Sol-Sc1-4] and [Sol-Sc1-6] had troubles when indicating the ‘id’ for each snippet. For instance, participant 9 pointed out: “what does ‘id’ mean in the different targets?” [Observer 2].

Task protocol induced some issues to the participants during the design process. Participants felt lost because we did not offered any guidance during the task: “at the beginning I did not understand anything” [Postest-3], “I have some problems to start designing the game, I wasn’t sure what to put in each snipped” [Postest-2], “I understand the scenario of the game but now, which targets do I take?” [Observer 1]. However, after some clarifications, all of the participants agreed that they were able to propose a solution: “once you understand the mechanics, it is easier” [Postest-4], “the process is through repetitions, so one can easily become familiar with the process” [Postest-5], “It presents a clear structure” [Postest-9].

Finally, all participants agreed that they would like to design their own games and test them with their students. Besides, when asking the participants how much they would devote to designing their own puzzle-based games according to our conceptual model, the average was half a day [Postest-all]. Some comments were: “If it is effective, I would devoted as much time as it was necessary” [Postest-4], “I don’t care, I would expend as much time as I need” [Postest-11].

Conclusions

The literature and the feedback provided by the teachers in the presented exploratory study agree on the importance of the problem addressed in this paper. Despite the potentially effective learning benefits of educational games, teachers do not apply widely these games in their teaching. Only occasionally they use mainstream games, such as mind games or puzzle games. The adoption is not extensive, because game designs are not always aligned with the requirements of the specific educational situations faced by the teachers and because the existing authoring tools are still too complex for teachers (Tornero et al., 2010). Creative teachers do devote time to design paper-based games for their classrooms but they do not typically have the advanced technological skills that would enable them the design of computer games.

As a first step to work towards solutions that tackle this problem, in this paper we focus on puzzle-based games. The simplicity and generality of puzzle-based games makes reasonable for teachers to act as their designers. We contribute with a model (conceptual model and XML information binding) that enables expressing diverse types of puzzle-based games including virtual and physical objects. As shown in the paper, the games that can be computationally represented with the model share the basic rules of games (e.g., scoring and hint mechanisms) and puzzles (e.g., interrelating pieces, considering slots) but allow different types and nature of content (e.g., contextualized in locations, tangible, completely virtual). In this line, the framework proposed by de Freitas & Oliver (2006), has been useful to define the general elements needed to conceptualize puzzle games independent from context and interactions, while considering the player’s role and activity flow. Besides, focusing on activity flow design, both Game Achievement Model (Amory & Seagram, 2003) and IMS Learning Design (Koper & Olivier, 2004) have been worthy examples to structure and interrelated the different elements of our proposed model.

To evaluate to what extent teachers are able to use and understand the different elements of the conceptual model, we carried out an exploratory user study with teachers from secondary and higher education. In particular, two different scenarios were proposed as game design tasks. The overall percentage of conformity for the first scenario (when compared to a prototype solution) was of 76%, whilst in the second scenario was of 85%. The degree of achieved conformity is valued as satisfactory, given that it was the first time the teachers were using the model (still low familiarity) and considering the limitations associated to the experimental design (snippets vs. proper authoring tool). The aspects of the model that hindered a complete conformity were related to difficulties in understanding the differences between activities' flows and single activities, and the virtual and tag attributes for pieces and slots. We will consider these details to refine how the model will be implemented in an authoring tool.

References

Avouris, N., & Yiannoutsou, N. (2012). A Review of mobile location-based games for learning across physical and virtual spaces. *Journal of Universal Computer Science, 18*(15), 2120-2142.

Amory, A., & Seagram, S. (2003). Educational game models: conceptualization and evaluation. *South African Journal of Higher Education, 17*(2), 206-217.

Bohn, J. (2004, April). *The smart jigsaw puzzle assistant: Using RFID technology for building augmented real-world games*. Paper presented at the 2nd International Conference on Pervasive Computing, Vienna, Austria.

Bottino, R. M., Ferlino, L., Ott, M., & Tavella, M. (2007). Developing strategic and reasoning abilities with computer games at primary school level. *Computers & Education, 49*(4), 1272-1286.

Cardona-Serra, J. (2012). *Design, implementation and evaluation of a tangible game based on puzzles to learn ICT-related concepts* (Final Project Degree). Polytechnic School, University Pompeu Fabra. Retrieved from http://www.recercat.net/handle/2072/205819

Chang, C. Y., & Sheu, J. P. (2002). Design and implementation of ad hoc classroom and eSchoolbag systems for ubiquitous learning. *IEEE international workshop on wireless and mobile technologies in education*. doi: 10.1109/WMTE.2002.1039215

Conway, M., Audia, S., Burnette, T., Cosgrove, D., & Christiansen, K. (2000, April). *Alice: lessons learned from building a 3D system for novices*. Paper presented at the SIGCHI Conference on Human factors in computing systems, The Haghe, The Netherlands.

Crawford, C. (1982). *The art of computer game design.* Berkeley, CA: Osborne/McGraw-Hill.

de Freitas, S., & Oliver, M. (2006). How can exploratory learning with games and simulations within the curriculum be most effectively evaluated?. *Computers & Education, 46*(3), 249-264.

Derntl, M., Neumann, S., Griffiths, D., & Oberhuemer, P. (2012). The conceptual structure of IMS learning design does not impede its use for authoring. *IEEE Transactions on Learning Technologies*, 5(1), 74-86.

Facer, K., Joiner, R., Stanton, D., Reid, J., Hull, R., & Kirk, D. (2004). Savannah: mobile gaming and learning? *Journal of Computer Assisted Learning, 20*(6), 399-409.

Falkner, N., Sooriamurthi, R., & Michalewicz, Z. (2010). Puzzle-based learning for engineering and computer science. *Computer, 43*(4), 20-28.

Fisch, M.S. (2005). Making educational computer games educational. *Proceedings of the 2005 conference on Interaction design and children*. doi: 10.1145/1109540.1109548

Hjert-Bernardi, K., Melero, J., & Hernández-Leo, D. (2012). Comparing the effects on students' behavior of two hint techniques embedded in a digital game-based learning tool. *IEEE International Conference on Advanced Learning Technologies* (pp. 138-140). doi: 10.1109/ICALT.2012.59

Huang, O.W.S., Cheng, H.N.H., & Chan, T.W. (2007). Number jigsaw puzzle: A mathematical puzzle game for facilitating players' problem solving strategies. *Proceedings of the The First IEEE International Workshop on Digital Game and Intelligent Toy Enhanced Learning*. doi: 10.1109/DIGITEL.2007.37

Ingalls, D., Kaehler, T., Maloney, J., Wallace, S., & Kay, A. (1997). Back to the future: the story of squeak, a practical smalltalk written in itself. *ACM SIGPLAN Notices, 32*(10), 318-326.

Jenkins, H. (2002). Game theory: How should we teach kids Newtonian physics? Simple. Play computer games. *Technology Review, 29*, 1-3.

Kaltenbrunner, M., & Bencina, R. (2007). ReacTIVision: A computer-vision framework for table-based tangible interaction. *Proceedings of the 1st international conference on Tangible and embedded interaction*. doi: 10.1145/1226969.1226983

Kelle, S., Klemke, R., Gruber, M., & Specht, M. (2011). Standardization of game based learning design. *International Conference on Computational Science and its Applications* (pp. 518-532). doi: 10.1007/978-3-642-21898-9_43

Kirriemuir, J., & McFarlane, A. (2004). Literature review in games and learning. *A report for NESTA Futurelab*, retrieved July 29, 2013, from http://archive.futurelab.org.uk/resources/documents/lit_reviews/Games_Review.pdf

Koper, R., & Olivier, B. (2004). Representing the learning design of units of learning. *Educational Technology & Society*, 7(3), 97-111.

Lee, H.S., & Lee, J.W. (2008). Mathematical education game based on augmented reality. Technologies for e-learning and digital entertainment. *Lecture Notes in Computer Science, 5093*, 442-450.

Li, Y., Fontijn, W., & Markopoulos, P. (2008). A tangible tabletop game supporting therapy of children with cerebral palsy. *Proceedings of the 2nd International Conference on Fun and Games*. doi: 10.1007/978-3-540-88322-7_18

Liu, T. C. (2007). Teaching in a wireless learning environment: A case study. *Journal of Educational Technology and Society, 10*(1), 107-123.

McFarlane, A., Sparrowhawk, A., & Heald, Y. (2002). *Report on the educational use of games. An exploration by TEEM of the contribution which games can make to the education process*. Retrieved July 29, 2013, from http://educationarcade.org/files/videos/conf2005/Angela%20MacFarlane-2.pdf

Melero, J., Hernández-Leo, D., & Blat, J. (2011, October). *A review of scaffolding approaches in game-based learning environments*. Paper presented at the 5th European Conference on Games Based Learning, Athens, Greece.

Melero, J., Hernández-Leo, D., & Blat, J. (2012). Considerations for the design of mini-games integrating hints for puzzle solving ICT-related concepts. *IEEE International Conference on Advanced Learning Technologies* (pp. 138-140). doi: 10.1109/ICALT.2012.60

Melero, J., Hernández-Leo, D., & Blat, J. (2013). Puzzle-based game mechanisms applied to in-situ indoor formative assessment. Manuscript submitted for publication.

Michalewicz, Z., & Michalewicz, M. (2008). *Puzzle-based learning: An introduction to critical thinking, mathematics, and problem solving*. Melbourne, Australia: Hybrid Publishers.

Mitchell, A., & Savill-Smith, C. (2004). The use of computer and video games for learning. *Learning and Skills Development Agency*,. Retrieved July 29, 2013, from http://www.m-learning.org/docs/The%20use%20of%20computer%20and%20video%20games%20for%20learning.pdf

O'Malley, C., & Stanton-Fraser, D. (2004). *Literature review in learning with tangible technologies*. Retrieved July 29, 2013, from http://archive.futurelab.org.uk/resources/documents/lit_reviews/Tangible_Review.pdf

Overmars, M. (2004). Teaching computer science through game design. *Computer*, *37*(4), 81-83.

Ponz-Adán, A. (2012). *Design, implementation and evaluation of a tangible game based on puzzles to learn computer architecture concepts* (Final Project Degree). Polytechnic School, University Pompeu Fabra. Retrieved from http://www.recercat.net/handle/2072/205818

Prensky, M. (2001). *Digital game-based learning*. New York, NY: McGraw Hill.

Sandford, R., & Williamson, B. (2005). *Games and learning a handbook from futurelab*. Retrieved July 29, 2013, from http://archive.futurelab.org.uk/resources/publications-reports-articles/handbooks/Handbook133

Santos, P., Llobet, W., Hernández-Leo, D., & Blat, J. (2009). QTI for self-assessment and embedded-assessment in competence oriented scenarios: The Agora Case. *International Conference on Intelligent Networking and Collaborative Systems*. doi: 10.1109/INCOS.2009.24

Spikol, D., & Milrad, M. (2008). Combining physical activities and mobile games to promote novel learning practices. *Proceedings of the Fifth IEEE International Conference on Wireless, Mobile, and Ubiquitous Technology in Education* (pp. 31-38). doi: 10.1109/WMUTE.2008.37

Squire, K., & Jenkins, H. (2003). Harnessing the power of games in education, *Insight, 3*(1), 5-33.

Tornero, R., Torrente J., Moreno-Ger, P., & Fernández-Manjón, B. (2010). e-training DS: An authoring tool for integrating portable computer games in e-learning. *9th International Conference on Advances in Web-Based Learning* (pp. 259-268). doi: 10.1007/978-3-642-17407-0_27

Torrente, J., del Blanco, A., Marchiori, E. J., Moreno-Ger, P., & Fernández-Manjón, B. (2010). <e-adventure>: Introducing educational games in the learning process. *IEEE EDUCON Global Engineering Education Conference* (pp. 1121-1126). doi: 10.1109/EDUCON.2010.5493056

Williamson, B. (2009). *Computer games, schools, and young people. A report for educators on using games for learning.* Retrieved July 29, 2013, from http://archive.futurelab.org.uk/resources/documents/project_reports/becta/Games_and_Learning_educators_report.pdf

Wood, D. J., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychiatry and Psychology, 17*(2), 89-100.

Yang, H. C. (2005). A general framework for automatically creating games for learning. *Proceedings of the* Fifith *International Conference on Advanced Learning Technologies* (pp. 28-29). doi: 10.1109/ICALT.2005.8