MuseumScrabble: Design of a mobile game for children's interaction with a digitally augmented cultural space

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ABSTRACT

Mobile technology has created new possibilities for location-based playful learning experiences. This paper describes the MuseumScrabble mobile game, aimed at children visiting a historical museum. The game requires that the players should explore the museum and link abstract concepts with physical artefacts using a mobile device. The focus of this paper is on the interaction design process and the subsequent observations made during field evaluation of the game. Design principles that guide the development of such a game are presented and concern playfulness, learning, social interaction, physical aspects of the game and flow between physical and digital space. We explore how these design principles are reflected in the study and how problem-solving strategies and collaboration and competition patterns are developed by children in this multi-player educational game.

Keywords: Mobile technology, mobile applications, mobile game, museum, design, digitally augmented space

INTRODUCTION

Mobile technologies play an increasingly important role in children's lives today. So it is reasonable to seek new ways in which this technology, now familiar to children, may be used for playful learning. An interesting example is location-sensitive mobile games that provide opportunities to embed learning in authentic environments while children have an engaging and joyful experience. Design and evaluation of such location sensitive games is a challenging process. The complexity of the settings for which the activity is designed and of the technology used, the special characteristics of the users, who are usually children, and the dual objective of designing a joyful and at the same time rewarding experience, mean that some basic principles need to be defined in order to drive the process. These tenets then inform major design decisions. Evaluation of the effectiveness of the technological and organizational decisions needs to be done in a systematic way and lessons learned need to be abstracted so that they may be useful for designers of other similar activities.

In this paper we discuss the design and evaluation of MuseumScrabble, a new location sensitive mixed reality game designed for children visiting a museum. The game is deployed in the historical and cultural Museum of Solomos and Eminent Zakynthians in Zakynthos, Greece. The museum hosts paintings, personal belongings and other artefacts mainly related to prominent people of the region, from the last three centuries. These non-interactive

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exhibits have been augmented with RFID tags and the museum equipped with a wireless network. The visitors of the museum may use handheld devices (PDAs) with RFID scanners to scan the tags and receive information as audio, text and images over the wireless network.

In this context the MuseumScrabble game has been implemented. The game has been named after the popular Scrabble word game, on which it is loosely inspired. The idea of associating the letters placed on the board to any word under the precondition that these letters are contained in the new word is transferred in the MuseumScrabble where the exhibits of the museum can be associated to an abstract concept, under the precondition that there is something common between the exhibit and the concept.

The MuseumScrabble game is played by teams who compete against each other. Each team is given a single handheld device with an RFID scanner through which they link exhibits to topics. The players select a topic, then move around the museum halls to identify the most relevant exhibits using the hints provided. The teams are free to select the topics they wish to play with. Examples of topics include: Ladies of Zakynthos, Religious art, Theatre etc. The teams that identify relevant exhibits are awarded points. The team that has achieved the highest score when the game finishes wins the game.

The objective of this paper is to describe the principles on which the design of MuseumScrabble was based and then provide an outline of key design decisions and discuss the effect these decisions had on children's behaviour when they played the game. The rest of this paper is organized as follows: Next, related work is presented, followed by the principles that informed our design and the discussion of how they influenced the design process. Finally the findings of an ecologically valid study of playing the game is discussed.

Related work

Location based activities can take place in museums and in general, in sites of historical, cultural or natural interest, where learning is combined with fun beyond the frames set by formal education (Hall & Bannon, 2005; Leinhardt, Crowley, & Knutson, 2002). Museums and other places of culture are already acquainted with mobile technologies, as handheld guide assistants have already been used for creating visitor experiences, beyond the typical visit (Schauble et al., 2002). In recent years there has been a visible evolution in the way mobile guide systems are integrated in museums, with social interaction and collaboration increasingly gaining in importance (Schroyen et al., 2008). For instance, mobile guides designed for group interaction such as "Sotto Voce" show a shift from simple information delivery to collaboration. Collaborative games provide a gameplay approach to the museum visit (Woodruff, Aoki, Hurst, & Szymanski, 2001). For example, the "CoCicero" project (Dini, Paternò, & Santoro, 2007) requires that visitors gather clues to solve a puzzle, while "Mystery in the Museum" requires that visitors collect, share and discuss about clues hidden in exhibits (Cabrera et al., 2005).

Another class of games has characteristics of a treasure hunt and usually takes place outdoors. An example is the "Mapping Challenge", a collaborative location aware interactive game that requires coordination between spatially separated members of a team in order to complete tasks (McGreen & Sáánchez, 2005). The "Frequency 1550" game about medieval Amsterdam is to be played during a single school day throughout the historic centre of the city by groups of 4-5 players (Huizenga, Admiraal, Akkerman, & ten Dam, 2009). It is argued that in these examples modern mobile devices allow users to play games that incorporate knowledge of their physical location and landscape, and then provide them with the ability to interact with both real and virtual objects within that space (Rashid, Mullins, Coulton, & Edwards, 2006).

These characteristics have influenced the design of MuseumScrabble. As a location based mixed reality game, MuseumScrabble has most of the characteristics of the so-called

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pervasive or mobile games (Hinske, Lampe, Magerkurth, & Röcker, 2007), integrating the physical and social aspects of the real world into computer games (Benford, Magerkurth, & Ljungstrand, 2005). Moreover, the pedagogical value of the activity which involves relating abstract ideas with physical objects adds a new challenge for the design of games in cultural spaces, as discussed in the following section.

DESIGN PRINCIPLES

The hypothesis behind designing MuseumScrabble is twofold: first, that an engaging learning activity in a traditional historical museum can occur when exhibition items are associated with familiar or abstract concepts (Hein, 1995) and second, that the effect of this association is enhanced when active participation is involved (Hooper-Greenhill, 1999). The MuseumScrabble activity offers to players a number of abstract concepts and awards them with points if they associate them with exhibits in a meaningful way. These abstract concepts, which are called topics, can be related with exhibits in various ways. Topics and exhibits might be related based on properties such as colour or theme or relation to other common characteristics. The educational aim is to help game players focus on specific information about a set of key exhibits, reflect about this information and use their imagination and their observation skills as tools for searching and finding relevant exhibits in the museum.

During the design process, discussion about the characteristics of the game evolved around three factors: a) the context, i.e. a traditional historical museum with non-interactive exhibits, b) the technology at hand, i.e. mobile devices to enrich the experience of visiting the museum and to interact with the exhibits, c) the goal of creating a learning game, i.e. interweaving learning with play and adopting a learning theory to be supported by the game. We further elaborated on these three factors to formulate a set of design principles that guided our design process.

Principle 1: Joy and playfulness

MuseumScrabble should be a tool that employs the fun of a game, so that the young visitors can get acquainted with the exhibits of a museum. Many studies stress the importance of employing games in the learning process focusing on the intrinsic motivation inherent in the nature of games (Malone, 1982). Gameplay is inherent in children and adults and, besides being a recreation, it promotes physical and intellectual activity. Interweaving the game idea with the content or the concepts to be learned is a way of infusing the advantages of games (i.e. the motivation derived from the feeling of fun) into the learning process (Malone & Lepper, 1987). In order to achieve a successful mix between learning and gameplay in an educational activity, some approaches suggest characteristics or *game elements* to be included in the activity. As Prensky (2005) notes, while "these elements are indeed found in good games, just having a list of elements does not guarantee a good game".

Instead, the approach suggested and the one followed here is to capture successful game styles from known gaming paradigms, like the scrabble in our case. Specifically, the challenge of the game is built around score-keeping and the search for exhibits, using given information in the form of hints.

Principle 2: Learning trajectories

Context, according to the theory of situated learning (Lave & Wenger, 1991), plays an important role in learning by providing tools, relevant background and learning objectives that give meaning to the learner (Lave & Wenger, 1991) . Learning in a museum evolves around non linear interaction with the exhibits (Hein, 1995; Leinhardt et al., 2002), thus the learning trajectories we aim at supporting consist of the following elements: a) observing the

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details of the exhibits, b) placing the exhibits in context (spatial, conceptual, thematic, historical) c) analysing and handling the information about the exhibits. In this context and with the use of technology we expect that players will engage in decision making (Which topic do we select? How much time do we spent on searching for an exhibit? How do we work as a group?) and formulate problem solving strategies.

The players discover items in the physical space and combine them with constructs, which in some cases can be abstract concepts, in a meaningful and score-yielding way. In order for this to be effective, a random strategy, where a player is blindly associating exhibits with concepts, should be discouraged. To induce players into exerting cognitive effort, the number of meaningful compared to that of meaningless possible associations should be small, so that players who can uncover relationships by observing, reading and reflecting on the items have an advantage. As an additional effect, the physical effort a player has to exert in order to discover an exhibit and associate it, acts as an enhancing factor on the learning process: The act of linking exhibition items with other concepts is underlined by the physical act of having to actually move in front of an exhibit and interact with it.

Principle 3: Social interaction

Considering gameplay, learning and museum visits as social experiences (Leinhardt et al., 2002), competition and collaboration become important components of an educational museum game. Possibilities for game-oriented and purposeful social interaction should be incorporated in the game (Jegers, 2007). To that end, the formation of teams can create opportunities for competition and collaboration. Competition among teams has a motivational effect and induces team members to collaborate in order to devise and implement new strategies to prevail in the game.

Competition can be fine-tuned by providing or limiting the awareness mechanisms, which show or hide the other players' activities. In the physical domain, the players can watch each other's activities, movement and conversations and so get implicit information on the evolution of the game. In the digital domain, the awareness mechanisms can convey status information that complement the physical channel and this flow of information can alter the game characteristics, for example current score, activity of the opponents etc. Collaboration can be imposed on the team members by creating situations in which they need to negotiate roles and strategies, e.g. such a situation arises from having one device per team, thus the question of who will operate it has to be negotiated.

Principle 4: Focus on the physical aspects of the game

The physical attributes of the space and of the exhibition items are part of the game mechanics and the game designer can use them to adjust the character of a game session. In contrast with the traditional gaming context, where non-game interactions are minimized, a game in a digitally augmented space incorporates the surroundings (Magerkurth, Cheok, Mandryk, & Nilsen, 2005).

Physical properties that can influence the way the players perceive relationships between exhibits and concepts are for example the distances between relevant exhibits; exhibits that are closer to each other are easier to associate. Similarly, some exhibits are easier to associate with given concepts due to their appearance, colour or other distinguishing characteristics that are easily perceivable. Other items require additional cognitive effort from the player, e.g. to use the handheld to access and read item descriptions. Finally, additional meaning is conveyed by the placement of the exhibition items in an area, which usually follows thematic considerations such as a certain period, or an event or style etc. This physical context of an item promotes some associations with concepts and discourages others, e.g. the placement of

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a painting in a room concerning a military event has different connotations as when the same painting is placed among paintings with a similar style.

Principle 5: Flow between physical and digital space

The design is driven by the aim to support a fluid interaction across the physical and the digital domains, which constitute the digitally augmented space: On the physical space of the museum, the items that populate it, their properties and the persons that interact with it, a digital layer is superimposed, defined by the digital content, the devices and the infrastructure that supports the interaction. A fluid interaction perspective treats the digitally augmented space as a whole and aims at a continuous experience. This continuity can be hindered by various aspects, especially when interaction occurs in the boundaries of physical and digital domains. Cross-domain operation can be unfamiliar to the users and may result in the shift of attention on interaction instead of the task (Rogers, Scaife, Gabrielli, Smith, & Harris, 2002).

Discontinuities that can arise from cross-domain interaction can be mitigated by the designer by choosing adequate interaction metaphors that support cross-domain flow. The scanner metaphor used in this case requires that one has close physical contact when interacting with an exhibit in order to receive related digital content. This rules out functionalities that are technically feasible but inconsistent with the metaphor, such as browsing through the exhibits by tapping on the PDA's screen, so the act of moving around the physical space appears self-evident to the users. In addition, special attention should be paid to digital content design, to avoid cases of breach of continuity across domains, as in the case of missing or mismatching digital content related to physical object.

THE DESIGN OF THE GAME

The design of this game was based on the main tenets discussed in the previous sections, while in addition, requirements and constraints related to the characteristics of the specific museum had to be taken into account. Such requirements were the low interactivity of the exhibits and the museum's wish to make only minimum changes to the exhibition. The game was required to reflect and respect the character and the narrative of the specific museum in terms both of content and aesthetics. Other requirements were that visitors should learn fast how to play the game and that the activity should not exceed the duration of a typical museum visit, leading to a play-time of up to 45 minutes. As the target players are children of late primary school up to lower high school ages (8 to 15), which are identified as rule/role and early adolescence stages by Markopoulos and Bekker (2003), the social dimension of the game needed to be particularly strong, as children of this age play in pairs and groups and become more interested in competition. So a fine balance of collaboration and competition needed to be foreseen in the game rules.

The design team included designers of different backgrounds, the first group of which was responsible for the activity design and conceptualization (Yiannoutsou, Papadimitriou, Komis, & Avouris, 2009) and the second one for interaction design and implementation of the game.

The game has been implemented as a real time networked multi-player application. A central game server coordinates the handheld devices. The handhelds were pen-operated PDAs running Windows Mobile 5 with a VGA touch-screen, to which RFID readers were attached. The game is not hard-wired and game scenarios (composed of topics, hints, exhibit descriptions, links scores) can be authored and played, that may target different age groups or focus on a different narrative. The head of a visiting party can choose which scenario the

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teams are going to play and can also author new ones in advance, using the available authoring tool.

An example of game activity

An example of game activity is given in this section, illustrated also in Figure 2 as a sequence of screenshots. A team decides to work on the topic "Women and Zakynthos". Next the team members have to decide on their strategy in order to identify the most relevant exhibits for each one of the topic's hints. If, for example, the first hint is examined ("the first woman feminist of Zakynthos"), provided that the players do not know beforehand who may be the first feminist of the region, then they have to search further among the exhibits, making some assumptions: When this person may have lived, what social class she may have belonged to, etc. The players have to scan candidate exhibits and look for further information either on the labels or in text on the screen of the PDA. For instance, in one of the halls of the museum there is a portrait of Elisavet Moutzan-Martinengou (1801-1832), an autobiographer, story writer, feminist, and woman of letters. The additional information is provided that "...many scholars consider E. Martinengou as the first modern Greek female writer and feminist". A lot of contemplation and physical movement in the halls of the museum is required in order to reach the portrait of this lady and find the relevant information so that the players can establish that the portrait matches the hint of "the first woman feminist of Zakynthos".

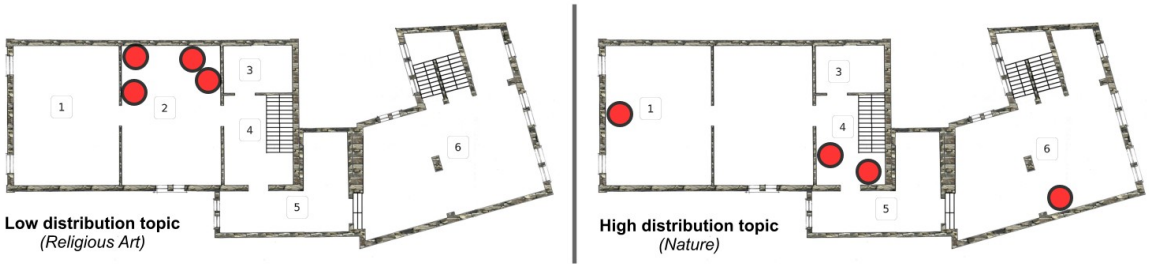

Figure 1: Spatial distribution of the exhibits: (a) concentrated topic (b) distributed topic.

The hint, once the team links it with the portrait, cannot be used by the other teams. However not all hints and topics are of equal degree of difficulty. There are topics, like "Animals", that can be identified easily by observing the exhibits, while others, like the example given on the topic of "Women and Zakynthos", need further search, involving in addition non-perceptual cognitive activity. Also the complexity of the task depends on the spatial distribution of the relevant exhibits of a particular topic. As shown in Figure 1, there are topics that are related to exhibits found in the same hall, while others are related to exhibits found in many distant places of the museum. No indication is given to the teams for the distribution of each topic, so they have to work on their strategies and decide on which criteria to base their decisions concerning topic selection.

User interface design

A description of the PDA's user interface during playing of MuseumScrabble is provided in this section as a series of screenshots in Figure 2. The interface consists of two screens. The t*opic selection screen* (on the left side of Figure 2) shows the available game topics in the form of thumbnails. Each thumbnail contains *colour flags* that indicate which teams have linked a hint in the particular topic. This awareness mechanism allows teams to have an overview of the game and of the progress of other teams, and helps them with selecting topics in which other teams are not active. After selecting a specific topic, the related e*xhibit association screen* is displayed. This screen contains a short description of the topic and the

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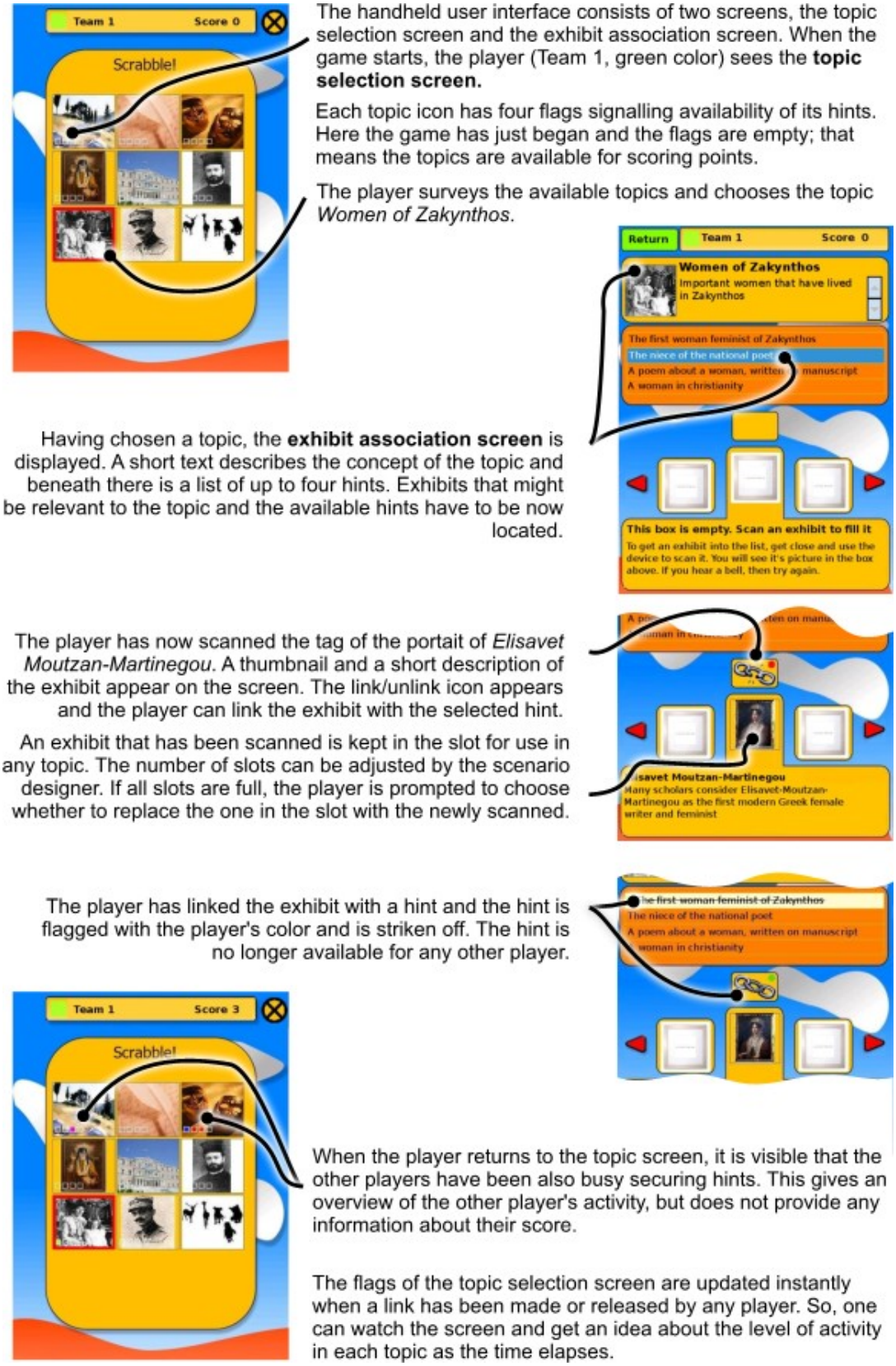

Figure 2: A sequence of PDA screenshots during a typical MuseumScrabble activity

list of hints for this topic and at the bottom of the screen the *slots* in which scanned exhibits are stored. Many such slots exist, through which the user can flip using the next/back arrows, however only three exhibits can be viewed at a time due to screen space limitations. Once an

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exhibit has been scanned, it is stored and the player can browse through the slots and bring it forward (in the central slot) and use for establishing a link. In order to link a hint to an exhibit, the player presses the *link button* and the currently highlighted hint is linked with the exhibit in the central slot. A link can be released only by the team which has created it. If the link is meaningful the team is awarded with points. The current score is displayed at the top of the screen.

The game design allows a number of alternative settings. These include the number of available slots for the scanned exhibits, so when the number of available slots is limited, the players have to move constantly and scan repeatedly, which requires more physical effort. Also the feedback when scanning unrelated exhibits affects the difficulty of the game, as if unrelated exhibits are allowed to be scanned, the search space increases. Finally the ending condition may change, as the game can end either when the resources (available hints) are exhausted or when a defined time span has elapsed.

The author of a MuseumScrabble scenario has to decide on these aspects and also define for what purpose and to which target group a specific scenario is aimed and adjust content and wording accordingly.

Figure 3: Kids playing the MuseumScrabble

FIELD STUDY

Outline - method of study

The game was tested in the field with the participation of children of the typical user age, see Figure 3. The game was played on a scenario that contained 9 topics, each with 4 hints. The 36 hints were equally divided such that 18 were designed as requiring perceptual skills from the players and 18 requiring additional cognitive effort. Out of the 140 tagged exhibits in the museum space, 36 were relevant to the game. 5 topics had their relevant exhibits concentrated in small areas and 4 topics were distributed over greater areas. When the devices scanned irrelevant exhibits a warning was issued, so the players were immediately informed about which exhibits could possibly yield points. The game interface allowed for scanning of up to 36 exhibits (i.e., 36 slots), so once a relevant exhibit was found, there was no need to scan it again.

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The study involved a group of 17 pupils from a local primary school (10 girls, 7 boys), aged 10-12 years. The players formed seven teams. Before the game they were allowed to use the electronic guide application, which runs on the same handhelds as the game, for about half an hour in order to become familiar with the exhibits, the handheld devices and the physical space of the museum. The participants had the following characteristics: All players had previous experience of the museum in the form of a guided visit and all had experience with game consoles in some form. 82% of the players stated that they regularly use a mobile phone, 53% of the players had used a PDA before the visit and 35% of the players had used a handheld device in the museum before. An instructor made a brief introduction of the rules before the game. After participants' consent was obtained, the activity was monitored through video using the museum's CCTV system and neck-hanging voice recorders. In addition screen recording and logging of events was performed throughout the activity. When the game finished, participants were asked to fill in a questionnaire relating to the game experience from the viewpoints of game comprehension, visual appeal and design, content accessibility, fun, motivation, competition. After that, the participants were debriefed in a semi-structured interview.

no	question	avg value	[reply]	stdev	n. of replies
1	The basic idea of the game was easy to understand	4.7	I fully agree/ agree	0.79	17
2	It was easy to learn how to perform the basic moves of the game	4.5	I fully agree/ agree	0.8	17
3	I liked the topics of the game	4.5	I fully agree/ agree	0.87	17
4	It was easy to understand the information on the screen while playing the game	4.4	I fully agree/ agree	1.15	16
5	I found the game visually appealing (colors, images, design)	4.3	fully agree/ agree	0.69	17
6	I had clear goals during the game	4.1	I agree	1.09	16
7	Some of the other players took the game too seriously *	3.9	I agree	1.03	17
8	It was easy to keep track of my successes or failures in the game	3.8	I agree	1.29	16
9	I was annoyed by people being in the same room as me	2.9	Indifferent	1.09	17
10	The other players didn't take the game as seriously as I did *	2.8	Indifferent	1.59	13
11	I did not have much to do during the game	2.7	Indifferent	1.49	17
12	The pace of the game was too slow	2.6	Indifferent	1.36	16
13	I found the game too difficult for me	2.5	Indifferent/ I disagree	1.15	16

Table 1: Post activity questionnaire (scale 1-5, 1 being fully disagree, 5: fully agree).

ANALYSIS AND DISCUSSION OF GAME PLAYING ACTIVITY

The game playing activity is analysed using the logged events that recorded the main actions of the players with the mobile devices. The logged events have been categorized as: (i) those regarding physical interactions and (ii) interactions in the digital space.

A physical interaction is logged when the player presses the hard button on the PDA in order to scan the RFID tag of an exhibit. A physical interaction also reveals the exact position of the player at the time of the scan.

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Interactions in digital space are actions performed with the stylus on the handheld's screen. In the analysis the actions studied were topic switching actions, recorded when a player enters or leaves a topic, and linking/unlinking actions, recorded when a player links an exhibit to a hint or releases a link.

In Table 1 an overview of the replies given in the post-activity questionnaire is shown, sorted in terms of the strength of the expressed opinion. The participants of the study answered 96% of the questions. The perceived view on the game design and game experience is reflected in the most favourably answered questions. The strongest opinion was related to the understandability of the game rules (question 1, strongly agree), learnability (question 2, strongly agree), interest (question 3, strongly agree), content understandability (question 4, strongly agree) and finally aesthetic quality (question 5, strongly agree). The above material is complemented by the video recordings and the transcripts of the audio recordings.

In the following, the activity is analysed according to the established design principles.

Joy and playfulness

At the end of the game it was found that three out of seven teams had not scored a single point. In games, this low performance is often an indication of low engagement and interest, resulting in lack of enjoyment and fun. This had to be further investigated, as it contradicted the visible enthusiasm of the players during the game and their answers in the post-activity debriefing that seemed to confirm their observed motivation.

Figure 4: The score the teams achieved vs. the performed linking/unlinking actions

By examining the relation between achieved score and the linking/unlinking actions performed (Figure 4), three clusters of teams emerge. The *experienced teams* cluster contains two teams that achieved high score (in average 22 points) with a higher effort. The members of these teams had stated in the pre-game questionnaire that they had experience with using the handheld device in this particular museum and also had more thorough knowledge of the museum collection, both of which can explain these teams' improved performance. The *inexperienced teams* cluster contains two teams that achieved lower score (in average 5 points) with less effort than the experienced teams. Finally the *unsuccessful teams* cluster contains the three teams that did not manage to gain any points at all, despite some activity similar to that of the inexperienced teams.

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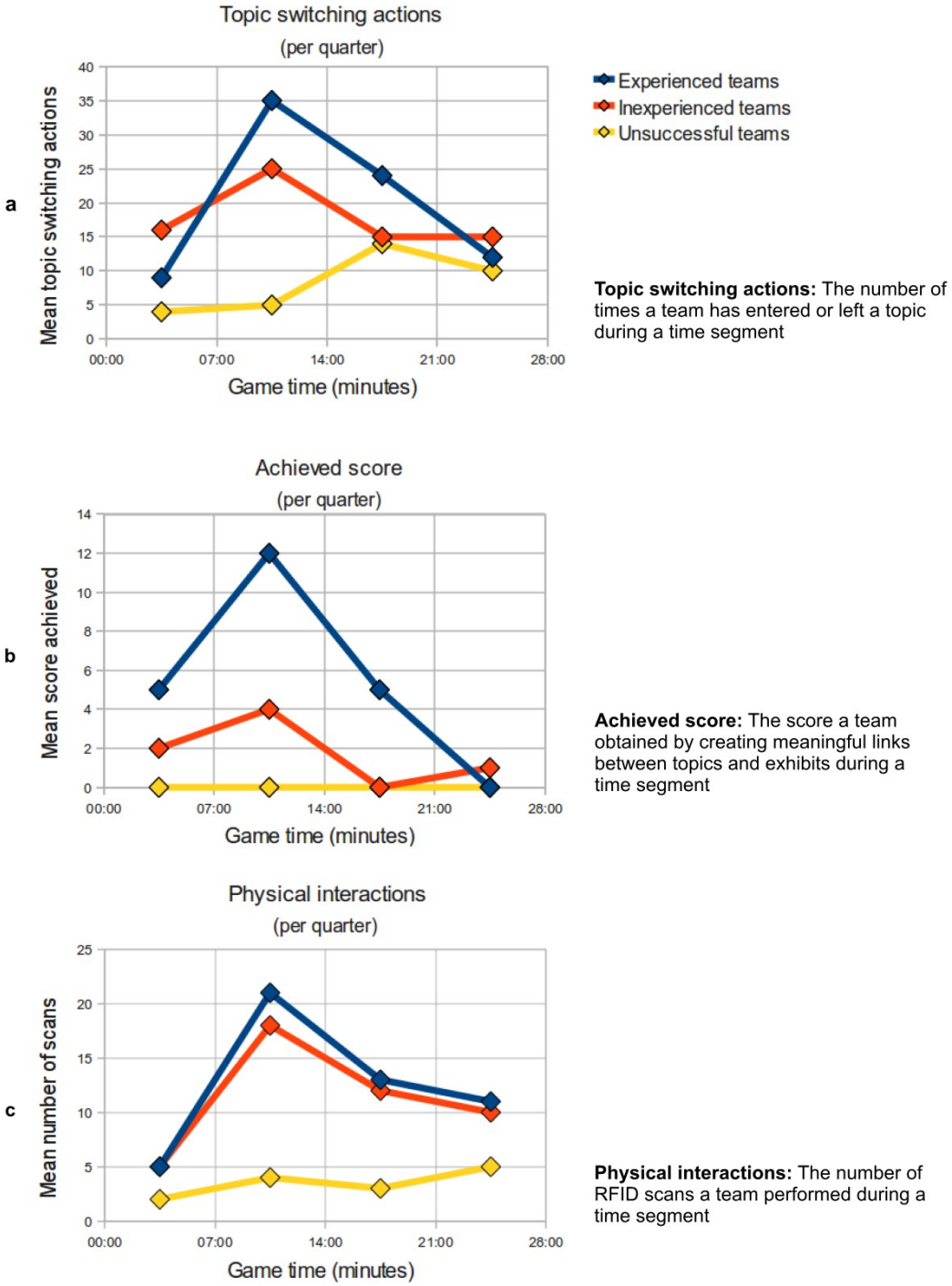

Figure 5: Activity of the three different team types during the game. Game time is divided in four quarters and the mean values for each quarter are shown.

Next, the evolution of the activity during the course of the game time is analysed. The total game time is divided in four quarters of approximately 7 minutes each, and the activity of the team clusters in each quarter is observed. The patterns that emerge are shown in Figure 5. Diagram 5(a) shows the number of *topic switching actions*. While all clusters started the game with a similarly low level of intensity in the first quarter of the game, the experienced teams found their bearings faster and became more active. The experienced and inexperienced teams show a visibly similar pattern throughout the game in all three diagrams. In contrast, the unsuccessful teams become active only after the first 15 minutes have

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elapsed. By that time, the most obvious links between hints and exhibits have already been taken by the other teams, so the remaining topics are harder to tackle (see also Figure 8) so these teams are not able to score any points.

The reason for this delay is attributed to the difficulties the unsuccessful teams had in understanding the game mechanics, resulting in their misunderstanding of functionality and game rules. Consequently, these teams needed more time to become active in the game and lost precious time in this competitive environment. Apart from this observation, three additional reasons have been identified, illustrated by observed behaviour patterns:

In the first case, players from one team interpreted some of the user interface conventions in a different way than intended by the designers. The linking button in the exhibit association screen showed a green or a red mark, for when the link was established and when the link was not established respectively (see Figure 2). These players interpreted the green mark as signifying that the link they created was valid and did not pay attention to the score, which remained zero (see dialogue exchange (3) in Table 2).

Second, while most of the teams started with the upper left topic of the overview screen, some of them spent proportionally too long a game time in that topic, loosing considerable time while the competitors moved to other topics. It could be that conventions again played a role and that these players chose to systematically go through the topics the same way one reads a book: By starting from the upper left corner. Another plausible explanation is that the game instructor biased these teams by using this first topic as an example to showcase the rules to the players before the game started.

Third, lack of collaboration was observed in one of the unsuccessful teams, when one of the players took hold of the handheld device and was fixated on finding the exhibit for one specific hint and ignored the calls of his team-mates (dialogue exchange (1) in Table 2).

The overall low activity of the unsuccessful teams can thus be interpreted as stemming from problematic understanding of the game mechanics and/or the lack of contextual knowledge required by the specific content.

In the post-game questionnaire, the questions regarding the dynamics of the activity (questions 9 to 13) were the most controversial (game challenge level, *I found the game too difficult for me*: average of 2.5 between *indifferent* (3) and *disagree* (2); *The pace of the game was too slow*: average of 2.6; *I did not have much to do during the game*: average of *2.7*). These questions were mostly negative statements, so the tendency is on the positive or indifferent stance. The strongest indications of game enjoyment and fun are conversely evident in statements of the players during the debriefing. Most notably some of them insisted that they had spent only five minutes playing, while the actual game time was around half an hour, a strong indication of achieving the objective of joy and playfulness.

Observed learning trajectories

Reflection on the participants' goals, according to the questionnaire, seems to have been on the positive side, as question 6 was answered mostly positively (*I had clear goals during the game*: average of 4.1, *I agree*).

The game was designed with a top-down strategy in mind, where the players pursue their goal by selecting a topic, searching for exhibits, creating links and so on. However, some of the teams switched to bottom-up strategies on various occasions; first scanning an exhibit and then flipping through the topics searching for a hint that can be used in a meaningful link. Team 3, as seen on Figure 6, switched from top-down to bottom-up strategy on two occasions, around minutes 3 and 14 of the activity: Instead of starting from a concept and then continuing to search the physical space for items that might match with it, Team 3, in these cases, first started from concrete exhibits and then tried to match them with concepts.

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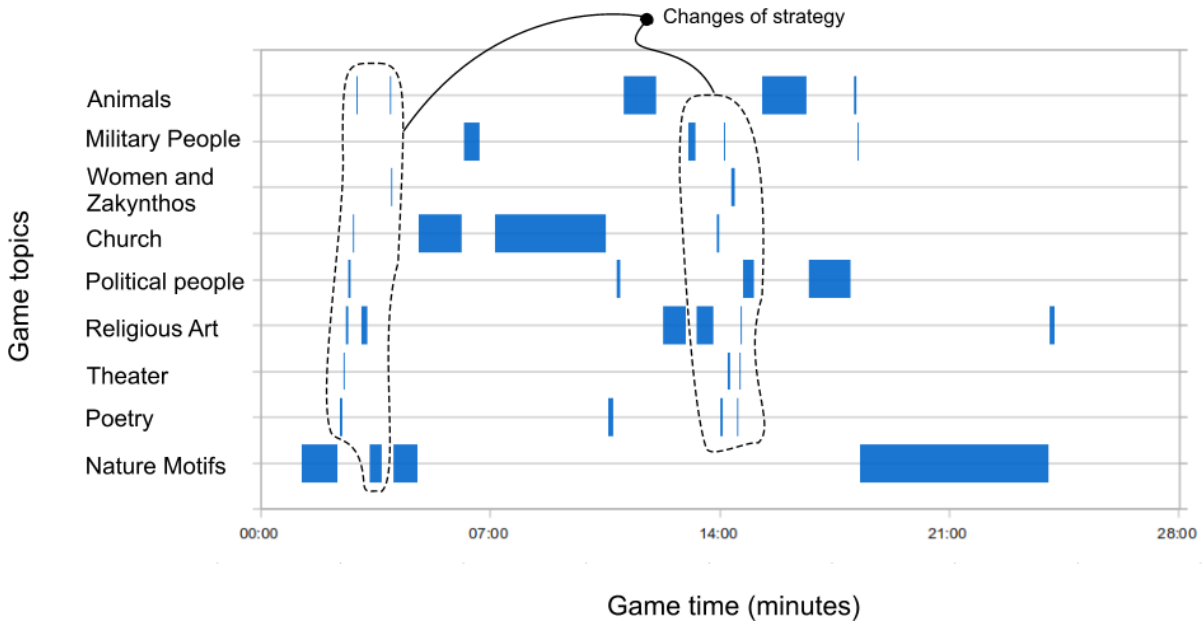

Figure 6: The topics on which Team 3 played during the activity. The marked areas show that the team changed strategy around minutes 3 and 14 of game time.

Another issue to be examined is whether the players were engaged in cognitive activity during game playing, as stated in design principle 2, or if they applied trial and error exhibit scanning actions in order to collect points. For this reason the strategy of a random player, who scans the exhibits and associates them with hints until successful, was simulated. The simulation ends once the random player has exceeded the highest score of the most successful team of the field study (26 points). It was found that the random player requires on average 710 actions for achieving 27 points (10000 iterations, stdev=80,9), compared to 35 actions of the cluster of experienced teams (see Figure 7). So the projected play time of this random strategy player would have been twenty times longer, i.e. around 10 hours, in order to achieve the same score as these teams, requiring 26 link/unlink actions for each gained score point. In contrast, the ratio of performed actions to achieved score in the experienced and inexperienced team clusters is low, in average requiring 1.6 link/unlink actions for each

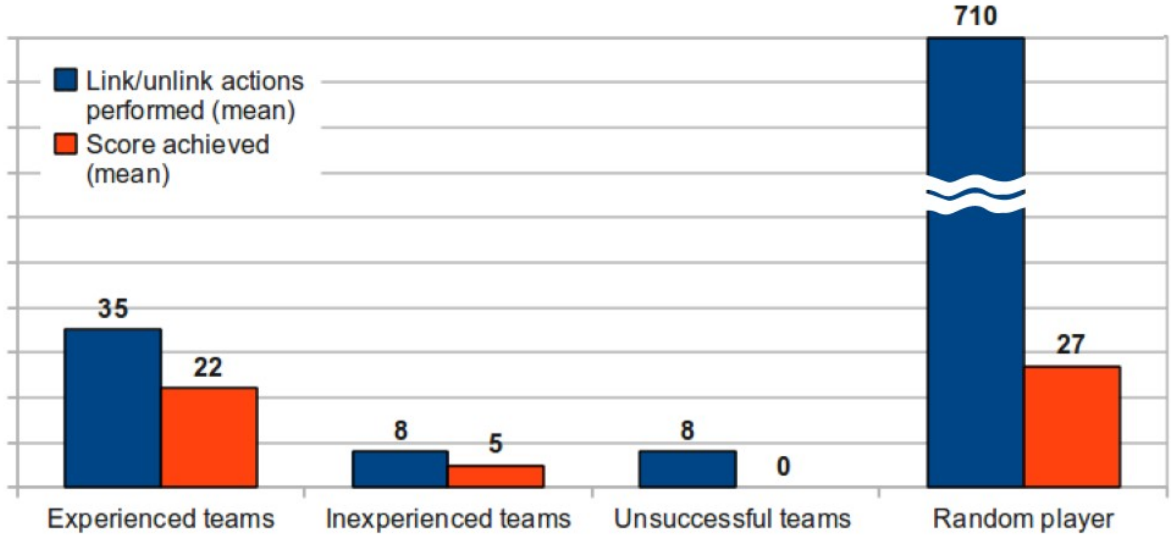

Figure 7: Achieved score per team cluster compared to a random strategy player

gained point. This clearly confirms that the players performed well-thought actions instead of attempting to link randomly.

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Social aspects

To increase the competitive nature of the game, the possible links between exhibition items and concepts were designed as a limited and exhaustible resource: Once a link is created, it is no longer available in the game, limiting the options of the competitors. The main objective was to balance competition and collaboration. Question 7 of the questionnaire (Table 1), if *some other players took the game too seriously* (3.9, I agree), serves as an indication of high competitiveness on the part of some teams. This should be related to the fact that each team had a different level of expertise. In particular, two teams scored much higher than the others, demonstrating strong competitiveness. Competition did act as a catalyst during game playing and induced strong feelings. In inter-team dialogue exchange (2) of Table 2, a question about current score is answered with hostility. This also shows how the designed lack of awareness about other teams' score induces the search for alternative sources of information.

Role allocation was evident in some teams, for example when a player handling the PDA instructed team-mates to go around the museum and spot exhibits that might be valuable in the game. In some cases however, lack of collaboration was observed within teams (e.g. dialogue exchange (1) of Table 2).

1. Lack of cooperation in a team:
   - (P1) *Can you give me the PDA for a bit?*
   - (P2) *No I can't.*
   - (P1) - addressing the instructor - *Miss, say something to Peter, he doesn't give us the PDA...*

2. Dialog between two competing teams:
   - (P1) *How many points have you got?*
   - (P2) *As many as we like, do you have a problem with that?*
   ....

3. Misinterpreting of interface conventions:
   - (P) *We have found one, but we got no points.*
   - (I) *Then the link isn't right.*
   - (P) *Why not right? We can see the chain.*
   - (I) *That doesn't mean it's right.*
   - (P) *The chain is green.*
   - (I) *Still, it doesn't mean it's right.*
   - (P) *Why?*
   ...

Table 2: Examples of recorded in-game dialogs. (P: Players, I: Instructor)

Physical aspects of the game

The evolution of physical activity in the game, as shown in Figure 5(c), is similar for the two successful team clusters. The RFID-scans were distributed in the physical space and not concentrated in smaller areas, meaning that the teams were actively searching the space for exhibits and interacting with them. Indeed, observational data and analysis of the children's activities in the captured video show that all teams were moving for most of the time.

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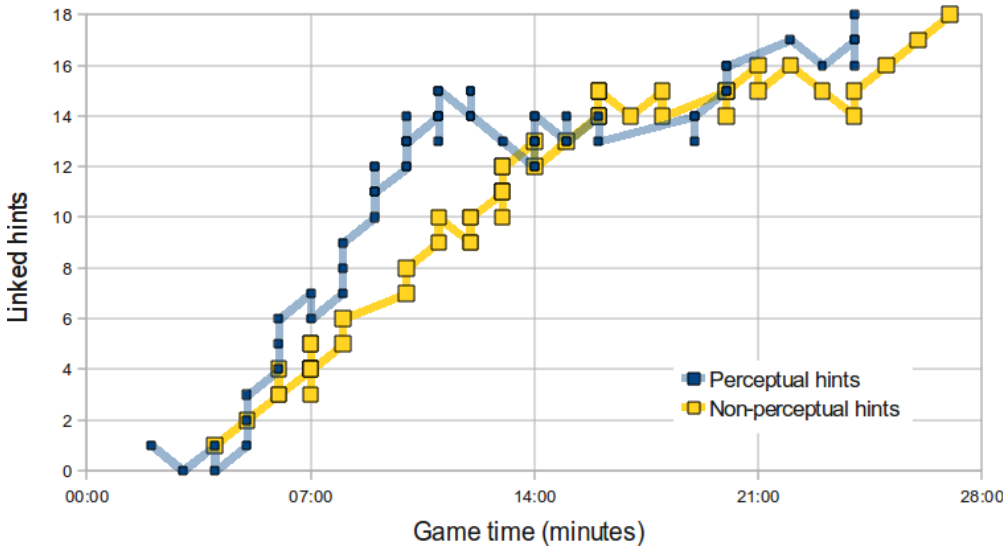

Figure 8: Evolution of number of linked hints during the course of

In general, the players displayed a preference for hints that required perceptual skills over hints that required additional cognitive effort. Figure 8 shows the increase of linked hints as the game progressed. The available perceptual hints are consumed faster in the first half of the game. Activity with perceptual hints prevails until the middle of the game session when only the most difficult hints remain available.

As a final observation, although the topics varied in terms of the spatial distribution of their relevant exhibits, the players had no way of knowing this in advance. Consequently they did not discriminate between topics that had their exhibits densely or sparsely allocated.

Flow between physical and digital space

The transitions between the digital and physical domains were most of the time continuous. The *scanner interaction metaphor*, used to facilitate the players' interaction with the exhibits as the act of moving close to an exhibit and using the device to scan it, was found easy to understand and to use, as is evident by the answers on question 2 (*It was easy to learn how to perform the basic moves of the game*: 4.5, *fully agree*). Indeed, the number of scan errors, produced when the scanning device is too far away from the RFID tag or at an improper angle, remained constantly low throughout the activity for all of the teams. The players also stated that the operation of the scanning device felt straightforward. This allowed them to treat the digitally augmented environment, that results from mixing physical and digital space, as a uniform domain. A strong evidence for this is the fact that they applied the same strategies on both the physical and the digital domains and for both the collaboration and the competition aspects of the game. Regardless to the task being to locate an exhibit in the physical space, match a hint or choose a topic in the digital domain, the team members applied similar collaboration patterns: first discuss and then act. Most interestingly, although the game designers designated the available hints as the only resource to compete for, placed in the digital domain, some players transferred competition on the physical domain: They attempted to stop their competitors from physically interacting with exhibits by standing in front of them, which incidentally is also an implicit but clear breach of rules.

The uniformity with which the players treated the digitally augmented space was disrupted when the digital content mismatched the players' expectations or perceptions of the physical space. When this mismatch happened, the players tried to resolve the disruption by retreating to the physical domain. Two examples of players facing such mismatches, breaking the game and seeking assistance, illustrate this: In the first case a bug in the MuseumScrabble interface

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prevented a description of a particular exhibit that the players had previously scanned to be displayed on the handheld's screen. In the second case, the players associated an exhibit with a hint and did not get the score they expected. The hint was about *birds* and the exhibit was a painting which contained a bird. The game scenario did not anticipate this exact association and there were no points awarded for it. In both these cases the players reacted assuming that there was a disturbance in the digital domain. While this assumption was correct in the case of the bug, in the second case they did not consider the possibility that they had got the wrong exhibit, or the wrong kind of bird, or that they might have misinterpreted the situation.

CONCLUSIONS

The MuseumScrabble game proved to be a joyful and engaging experience for the pupils who participated. The children were immersed in the activity, lost track of time and pressed the instructors for more gaming sessions. All players were fundamentally involved, even the ones whose teams did not score. They were engaged in cognitive activity and developed unanticipated strategies, thus a learning process was undoubtedly in operation. In general, strong competition was observed between teams and strong patterns of collaboration between team members. The players explored the museum space in a new way and discovered associations and relations between exhibits that transcended the strict physical constraints imposed by the exhibition layout. The physical and digital aspects of this pervasive activity were incorporated in a unified experience and the transitions between the digital and the physical domains were most of the time continuous. Thus, the heterogeneous design elements that were included in the design process were combined successfully and a balance between play and learning was achieved. This is the prime objective of an educational game.

Some cases of breaking the rules in the physical or digital domains were observed. This 'cheating behaviour' is typical of game activities, and ways of tackling it in terms of the sought learning effect of the activity (Consalvo, 2008) need to be taken into account and studied. Further, it was evident that when players with uneven skill levels engage in a multi-player activity that is limited in time, the inequalities can unbalance the benefits and diminish the satisfaction and sense of accomplishment for some of the players. Future research may be directed towards the inclusion of mechanisms for automatic difficulty adaptation in order to slow down the most successful players and avoid discouraging weaker players.

The ecologically valid field study provided a rich set of data, which allowed the subsequent analysis of the findings, although the learning effects were not measured in the present work. As a final note, it was found that the design principles used were able to produce a game that achieved a delicate balance between joy and learning and also between competition and collaboration. Thus, it is hoped that these principles can be applied in the design of other similar multi-player learning games in digitally augmented spaces in the future.

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