Explore! Possibilities and Challenges of Mobile Learning

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ABSTRACT
This paper reports the experimental studies we have performed to evaluate Explore!, an m-learning system that supports middle school students during a visit to an archaeological park. It exploits a learning technique called excursion-game, whose aim is to help students to acquire historical notions while playing and to make archaeological visits more effective and exciting. In order to understand the potentials and limitations of Explore!, our studies compare the experience of playing the excursion-game with and without technological support. The design and evaluation of Explore! have provided knowledge on the advantages and pitfalls of m-learning that may be instrumental in informing the current debate on e-learning.

Author Keywords
Mobile learning, edutainment, children, digital augmentation, cooperative inquiry.

ACM Classification Keywords
K.3.1 [Computer Uses in Education]: Collaborative learning-Distance learning.

INTRODUCTION
Until now, the use of computers in education has been focused on supporting learning in formal settings, such as classrooms or computer laboratories. However, one of the main advantages of e-learning is its independence of both time and location. Consequently, the use of mobile devices like smartphones could expand learning, freeing the user from ties to a particular location. The combination of e-learning and mobile computing is called mobile learning (*m-learning*) [14]; it provides opportunities to interact with learning materials in different ways while exploring a physical environment both outdoor (e.g. archaeological parks, woodlands) and indoor (e.g. lab, home) [25]. While mobile technology has the potential to offer many different levels of engagement, most applications simply use mobile devices to deliver the same content in the same way that is currently provided by more traditional e-learning [6]. One of the current challenges is to understand what content should be delivered by smaller devices and how it should be adapted to a specific learners' community.

In order to exploit the positive characteristics of mobile technologies for learning, new teaching/learning techniques must be defined [5]. This paper reports our experience with the design and evaluation of Explore!, a mobile learning system implementing a game to be played by middle school students during a visit to an archaeological park. Since Explore! targets children, it should be capable of arousing emotions, stimulating imagination and curiosity while keeping them focused on the task at hand. Distraction is one of the most important problems in m-learning: methods capturing students' attention and engaging them in the learning experience in a didactically correct way must be identified. Gameplay is a promising solution to achieve this goal, as it provides a structure and well defined rules to drive the user behaviour.

Explore! implements a novel learning technique inspired by the excursion-game proposed by researchers in Teaching History [7,8]. In order to understand the potentials and limitations of Explore!, we have conducted an empirical study that compares the experience of playing the excursion-game with and without technological support. The study shows that gameplay is able to motivate and engage students and to stimulate an understanding of history that would otherwise be difficult to engender, making archaeological visits more effective and exciting. Furthermore, the evaluation has provided some knowledge on the advantages and pitfalls of m-learning that may be instrumental in informing the current debate on the future of e-learning.

The following section motivates learning by gameplay, referring to related work. Then, we present Explore! describing the original excursion-game, its implementation on a cell phone and its design characteristics. The Section "Evaluation" reports the study carried out with students of a middle school and its theoretical background. The paper concludes by reporting implications for m-learning.

LEARNING BY GAMEPLAY

The latest hardware advances and the quest for successful learning techniques have led to the concept of *computer-based edutainment*, i.e. education in the form of entertainment, where learners can reach their learning goal while having fun [20]. Research indicates that well-designed computer games can meet some of the psycho-logical needs of children and motivate them to learn [11].

Play is a natural and universal behaviour of children and adults. Play allows people to make intellectual and physical exploration, extend their communication skills, give free rein to their imagination, manage their environment through cooperation, and carry out social problem-solving [23,24]. Enjoyment is important when endeavouring to achieve teaching goals, because what is enjoyably learned is less likely to be forgotten. Play is often a relational activity: it encourages group interaction, stimulates collaboration, helps with conflict management and is an excellent tool for individuating relational problems [26]. Group play requires different skills to be deployed simultaneously, and each player can practice those skills felt to be most congenial. Evidence of learning effectiveness of educational electronic games has been shown, primarily to teach mathematics [9], science [25], logic [18], art [16], history [15], and to shape writing [17].

Augmented reality (AR) games are a particular class of games. They embed virtual, location-specific and contextual information in a physical site. These games rely on the availability of mobile or ubiquitous computing devices, such as handheld computers or cell phones, to enable the players to access virtual information in a physical context [26]. Support for AR games derives from several pedagogical theories, including Constructivism and Situated Cognition. The Constructivist approach claims that learners actively construct their own knowledge, instead of passively receiving information from a teacher or guide. They learn cooperatively and socially, and by reflection upon their own learning process [26]. The Situated Cognition approach claims that student learning is more engaging when students have opportunities to draw on real world situations and especially on situations they are personally immersed in [1]. During AR game execution, students can effectively work together to solve problems and construct their own solutions, narratives, and connections, in the environment where they would typically occur [26]. Another factor supporting the use of games in education is the growing possession of mobile devices: wireless handheld devices, especially cell phones, are popular because of their relatively low cost, flexibility, networking capabilities, and portability.

Our game-based approach to m-learning has similarities with those described in [25] and in [16]. The “Ambient Wood” system aims to encourage children to carry out scientific enquiry while exploring different habitats in a woodland [25]. The system displays an image of a plant or animal together with a speech message about an aspect of its habitat. Wireless speakers are hidden in the woodland to provide a range of realistic sounds of the habitat. Two studies, involving 40 students aged 11-12 years old, highlighted that children were able to integrate findings and information obtained from the mobile device with their observations of the physical environment.

In [16], a PDA application, called “Mystery in the Museum” that stimulates collaboration of small groups of students, is described. Its aim is to augment interaction with the museum through a mystery play that stimulates children’s imagination. The plot involves a number of puzzles that relate to the exhibits of the museum and players are rewarded when they reach correct solution. The rewards help players to solve the whole mystery. The system was evaluated in a setting that resembled a typical context of use. An interesting result is that children lose interest in the game if it is too difficult to play.

EXPLORE!

Italy has a rich fund of cultural heritage, with many historical sites dating back to centuries B.C.. Among current visitors of these historical sites, families and students, especially middle school children, account for 80%. All the same, it is difficult to estimate how lasting an interest in archaeological parks and museums traditional visits can generate in students. In order to increase young people’s engagement, the visit must be supported by skilled guides who can foster the students’ interest and help them make sense of the ruins that have lost their original image. Given the richness of the Italian cultural heritage, and a chronic shortage of funding, it is almost impossible to provide this service in all archaeological parks, and many of them are left unmanned.

This situation motivated the design of Explore!, an m-learning system intended to improve the visitor’s experience of historical sites at a minimal cost. By exploiting the imaging and multimedia capabilities of the latest generation mobile devices, it is possible to create electronic games that can support learning of ancient history, by transforming a visit to archaeological parks and museums into a more complete and culturally rich experience. Explore! is inspired by the excursion-game technique proposed by Historia Ludens to support students during a visit of archaeological parks [7,8]. Historia Ludens is an association, set up by researchers in the field of Teaching History at the University of Bari, Italy. The experience with these excursion-games has been replicated hundreds of times with different classes and teachers, who greatly appreciated how much students were stimulated by the game to learn more about the site and overall how much they enjoyed the visit.

Gaius’ Day: the original game

Among the excursion-games designed by Historia Ludens for different archaeological parks in Italy, Explore! currently implements “Una giornata di Gaio ad Egnathia”

(Gaius' Day in Egnathia), which is designed for a visit to the archaeological park of Egnathia, an ancient city in the Apulia region [2,3]. Gaius' Day is structured like a treasure hunt to be played by groups of 3-5 students: it combines the excitement of chase and solving the case with the joy of freely exploring a place and discovering its hidden secrets. This type of game is well suited to the archaeological park context, with wide spaces where students can move about freely and use their intelligence and imagination to conjure up how life used to be there, by observing the site and memorizing places, names and functions. The students have to discover meaningful places in the park following some indications and then they have to mark the position of the place on the map. The game is supervised by a game master, whose main tasks are to check that the rules are correctly observed, encourage the group if they run into difficulties, and push them in the right direction by giving suitable hints. The whole excursion-game lasts about three hours. It consists of three main phases: 1) the introduction phase; 2) the game phase; and 3) the debriefing phase.

The introduction phase

After children arrive at the archaeological park, the game master gives a brief introduction to the place where the game is to be played and the historical period being studied. Then s/he explains the rules of the game and its phases. Groups of 3-5 players are formed: each group impersonates a Roman citizen, called Gaius, who has just arrived in Egnathia with his family. Group members play different roles, i.e.: the *reader*, who reads the challenge; the *petitioner*, who consults the glossary; the *navigator*, who carries the map and marks the identified places. The remaining members, if any, are the *scouts* who go on ahead to trace the places that are the targets of the mission.

The game phase

The group is provided with a "libellum", i.e. a booklet containing the challenge description, the map of the archaeological park and the glossary. The challenge description is provided in a narrative form set in the historical context, and contains a number of different tasks, called missions, that Gaius has to accomplish in his typical day. For example, a mission reads as: "You have to find a job for your sons. Look for the Trajan Way where many coaches travel. Someone could need your son's help to fix a coach wheel". The map allows the players to find their way around and to follow the right pathway. The glossary contains a detailed explanation of the places they will come across while playing the game, e.g. "Trajan Way was the main road crossing Egnathia; it was a paved road…".

To carry out the missions, players have to formulate hypotheses, discuss them, retrace their steps when they go wrong and correct their mistakes. When the group believes they have identified the target place, they mark that place on the map. If students have difficulties in solving a mission, they can ask the game master for help.

The debriefing phase

It is essential to follow up the game phase with a reflection phase, called debriefing, separate from the true game. In the excursion-game it is believed that learning happens mainly during this phase, when the knowledge acquired during the game is consolidated and integrated [8]. The debriefing is presented to the players as a pleasant end to their day and the experience they have had. Students are first asked how they feel about the experience, to sound out their emotional response. The students are invited to tell their own story, so that the group can recognize the common elements and discuss the specific aspects of each character. Then, they are asked how they imagine the city of Egnathia: the inhabitants, the houses, streets, buildings, etc. At the end of the debriefing, the experience is conceptualized. The game master gives a complete overview of the various notions they learned during the day and encourages them to ask questions, make hypotheses and satisfy their curiosity.

Playing Gaius' Day with Explore!

The final aim of Explore! is to provide a tool for any visitor of archaeological parks. We designed the current version of the system to evaluate the feasibility of mobiles for conveying the game challenge and of a set of digital instruments for improving the debriefing experience. This version of Explore! is still highly dependent on the presence of a skilled game master, but our ambition is to gradually decrease this dependency.

The introduction phase for the electronic version of the game remained unchanged: the game master explains the game and divides the participants into groups. Each group is given a cell phone and the map of the park. The cell phone is used as an instrument to communicate the challenge. Due to the display size limitation, the challenge is divided into separate units, corresponding to the missions. Missions are displayed as text messages and proposed to the players in a set sequence. To help students to carry out the game more rapidly and correctly, each mission is connected to the related glossary entry. This information, that gives students the right hint to help discover the place, can be accessed by selecting a menu item labelled "Oracle" (inspired by the Latin "Oraculum").

The system tells the players that they impersonate Gaius, who has to carry out some missions. Each group member plays a role: the reader holds the cell phone from which s/he reads the challenge, accesses the "Oracle", inputs the answers, while the navigator and scouts perform as in the original game. The system invites the group to start playing as soon as they are ready. A sound attracts players' attention while the first mission to be executed appears on the phone screen (Figure 1). The group walks around the ruins trying to identify the place the mission refers to. When students believe they have identified the target place of the mission, the reader digits the numerical code of the place, indicated in the park by small signs, on the phone. A system sound signals that the current mission is concluded and the next mission is beginning. It visualizes the text of the new mission and reads it out aloud to attract the attention of all group members.

After completing the last mission, the group receives “Gods’ gifts”, i.e. the 3D reconstructions of the places correctly identified. The students have the chance to interact with the 3D reconstructions on the phone and visually compare the possible ancient look with the existing remains (Figure 2). The proposed 3D models are scientifically correct, having been designed in collaboration with archaeologists of the Ancient History Department at the University of Bari, Italy, who are carrying out research projects on archaeological parks in Southern Italy.

Figure 1. A group performing the game.

Figure 2. The 3D reconstruction of the Trajan Way visualized on the phone (left) and the existing remains (right).

The debriefing phase is greatly augmented in the mobile version. During the game, information is recorded in an XML logfile: inserted codes, missions’ execution time, requests to the oracle, etc. A system component (called *Master Application*) running on notebook has been designed to empower the game master, who may replay the activities of the groups, based on the collected logfiles. S/he also presents 3D reconstructions of the historical monuments, which are shown in a much higher definition than the ones on the cell phone. The game master proclaims the winning group and, more importantly, recaptures some of the things learned throughout the visit. The *Master Application* also offers the game master and students the chance to play a “collective memory game” where monuments and archaeological objects (previously encountered by the students as part of the game) are to be placed in the “right” place on the park map.

Design and architecture

Explore! has been developed following a learner-centred approach [22], with the participation of pupils, teachers and Historia Ludens associates. Requirements were collected by contextual inquiry [10], observing pupils’ (10-12 years old) behaviour during the game in situ [2]. Moreover, formative evaluations involving middle school students were conducted throughout the design process [3]. The system has been designed to be easily adapted to different historical sites. An XML file determines the way historical information is presented and it can be authored in different ways.

The architecture of Explore! is aimed at reducing implementation costs and architectural complexity to absolve the archaeological park from any need to invest in hardware infrastructure. The main system components are the *Game Application* and the *Master Application*.

The *Game Application* runs on cell phones, that are very common among middle school students and so we can assume that at least one student in each group owns a phone. The game is provided on a phone memory card, which is handed out to each group at the start of the game session. All data exchange takes place between the cell phone and the memory card inside it: no data are transmitted from or to the phone during the actual game, thus reducing communication costs and time. The *Game Application* is developed using Java Micro Edition (J2ME). Three packages are requested, which are currently provided by default in cell phones supporting J2ME: JSR75 (for managing XML files), JSR184 (for visualizing the M3G files containing the 3D models), and JSR234 (for reproducing multimedia). In the study described in this paper, the game has been executed on a Nokia E70 handset, but it was also successfully run on a Nokia 6630. The 3D reconstructions of historical monuments were developed using 3D StudioMax and exported to the M3G file format.

The *Master Application* supports the debriefing phase. It resides on the game master’s notebook, equipped with either Bluetooth or a memory card reader, through which the application collects the logfiles from the groups, as they come in at the end of the game. Data in these logfiles are analyzed using statistics and visualisation tools.

EVALUATION

The main objective of the evaluation program in Explore! was to compare the pupils’ experience while playing Gaius’ Day in its original version with the experience of the electronic version of the game. The evaluation involved several stakeholders, ranging from students and teachers, to experts of teaching history, and archaeological park curators.

Based on the theory of distributed cognition [13], we expected that the change in the main artefact mediating the game would induce important differences in the players’ behaviour. Distributed cognition explains and models information processing and problem solving behaviour within groups of users supported by artefacts and tools. It extends cognitive processes beyond the individual actor and outside time and space. Cognition is regarded as the result of processes distributed across members of a group, supported by tools and artefacts. The bulk of the research applying distributed cognition to design has focused on functional tasks, with a major emphasis on improving usability and minimising workload. In this paper, we apply it to analyse also emotional and social variations induced by different artefacts in group problem-solving. In this systemic view, we expected that Explore! would have the following implications on the game.

Behaviour. The sequential nature of the game in Explore! would affect problem-solving strategies. This could lead to better performances, as the players' attention is focused on the current mission and all irrelevant information is filtered out. Conversely, the lack of contextual information could degrade performance, as fewer cues are available to solve the mission.

Engagement. Explore! will be more engaging than the original game, as it offers the possibility to record and replay participants' performance, as well as to interact with multimedia content in the field and during the debriefing.

Learning. The multimedia content proposed by Explore! will help users to form a clearer mental model of what life used to be like in ancient Roman times.

Pilot study

A class of 24 students was involved in a pilot study to evaluate the system reliability and research methodology (e.g., time constraints, coding techniques, video-recording activities). These students had already visited the archaeological park six months earlier, playing the paper-based game. Thus, they were in the position to compare directly the two experiences (original game vs. Explore!). Obviously, this comparison was hampered by the lack of counterbalancing and by the long time interval dividing the two experiences. The results need to be carefully weighted, but they furnished some interesting indications.

Procedure

The students were divided into 6 groups and 3 groups at a time played the game with Explore!. Each group was given a cell phone, a paper-based map, and was introduced to the game by the game master. Group members were assigned a role, but they were also told to feel free to swap roles during the game. Once participants believed they had solved the mission, they entered the numerical code denoting the place in the system. At this point, Explore! proposed the new mission. At the end of the game, students were invited to re-trace their path and when they arrived at the place they had identified, the reader would again insert the code. If the answer was correct, the device visualized the 3D reconstruction, otherwise an error message invited the students to ask the game master for an explanation during the debriefing. Participants were videotaped during the entire game and a dedicated observer for each group took notes on their behaviour.

Participants were debriefed with the support of the game master's notebook. Hence, they were exposed to the electronic map and the 3D reconstructions of the historical monuments. The day after the trip, students were given a written assignment requiring them to compare the original game with Explore!.

Results

The pilot study clearly demonstrated the pedagogical value of the excursion-game. All groups quickly solved the challenge (mean = 24.17 mins, std dev = 5.64) and it was clear from their behaviour that they had an excellent mental model of the place. They rarely read the map and often appeared to know where to go by memory. Only three mis-takes were made. The study also proved the technical reliab-ility and the usability of Explore!. All students learnt how to use it as soon as they received it, with no need for explana-tion. During the test, however, an interaction problem emerged, as the interface did not permit corrections. Once the participants had entered a code, they could not modify their choice. Unfortunately, the problem could not be fixed before the main evaluation study, but we dealt with it, invit-ing students to contact a technician in the case of errors.

The analysis of the essays indicated a positive reaction to Explore!. Some 74% of the students explicitly reported having preferred Explore!, 13% preferred the original game, whereas 13% did not express any preference. The 3D reconstructions on the mobile and during the debriefing were the primary reason for preferring Explore!. Another important reason was related to the convenience of the solution (fewer papers) as compared to the original game. Indeed, the paper-based game was tested on a windy day, which made reading from the paper quite complex. One reason for preferring the original game was the mismatch between the role-play game (pretending to be an ancient Roman citizen) and the technological medium. This inconsistency was nicely summarized by a student: *'Ancient Romans did not have mobiles!'*

Implications for the evaluation methodology

The pilot study provided some important suggestions for the design of the main evaluation study. In particular, it proved instrumental in defining the coding technique for standardizing observations. Our study involved a large set of evaluators: two experimenters for each group (one in charge of videotaping and one in charge of taking notes), plus four external observers who overlooked the study from the archaeological wall to get a comprehensive view of participants' behaviour. Hence, cross-rate reliability was a major issue.

After the pilot study we organized two meetings with all the evaluation team to identify salient behaviour and refine the evaluation grid. Several coding exercises were conducted on the videos to ensure that all experimenters would use the same coding procedure. The final observation tool addressed *social interaction*, *problem solving strategies*, and *interaction with the artefacts*.

The pilot study also allowed us to detect a major flaw in the evaluation procedure: all 3 groups playing simultaneously were given the same challenge. This created interference in game execution, and some students reported being upset that the others could copy their behaviour. To counteract this problem, in the final study we used 3 challenges differing in content, but not in complexity. They addressed a common set of targets in a different order and with different cues.

Evaluation study

This section describes the method applied in the final evaluation study. Where not otherwise stated, the procedure is exactly the same as in the pilot study. The hypotheses driving the study have already been stated at the beginning of the "Evaluation" Section.

Participants

The study involved two second year classes at the Middle School "Michelangelo" in Bari, Italy. A total of 42 pupils, aged 12, participated in the evaluation as part of their school-work. They were familiar with the use of PCs, cell phones, and had a previous experience of excursion-game played at a different historical site.

Procedure

Data collection took place on May 30th and 31st, 2007, at the archaeological park of Egnathia. A follow up session to evaluate learning was conducted on June 1st in school. The game type (paper-based vs. mobile) was manipulated between-subjects. Nineteen students, divided into 5 groups, played the paper-based version of the game; 23 students, divided into 6 groups, played the mobile version. Groups were formed by the teacher to guarantee social and cognitive homogeneity.

Participants assigned to the paper-based condition received the challenge description, the map, and the glossary. The mobile group received a cell phone and a paper-based map. To minimise interferences between groups in the archaeological park only 3 groups, belonging to the same game condition, were tested simultaneously. At the end of the game, participants answered a questionnaire addressing several aspects of the game experience.

The paper-based group was debriefed by the game master in the traditional way, while the mobile group was debriefed by the game master with the support of the *Master Application*. At the end of this phase, participants answered a questionnaire regarding a self-assessment of their learning. The mobile group also answered questions about the 3D reconstructions.

The next day at school, students were administered a test to evaluate the knowledge they had acquired during the game. They also composed essays and drew pictures about the experience at Egnathia.

Instruments

Measuring the user experience of m-learning games is a complex task and there is no consensus among researchers as to which specific techniques should be used [4]. In this study we have adopted a wide range of techniques including naturalistic observations, self-reports (questionnaires, structured interviews, and focus groups), post-experience elicitation techniques (drawings and essays), and multiple choice tests. A summary of the main factors addressed by our evaluation, along with the method and techniques applied is reported in Table 1.

Table 1: Summary of the instruments and techniques used during the evaluation.

Behaviour	Naturalistic observations; questionnaire; focus group; essays and drawings.
Engagement	Open and closed questionnaires; naturalistic observations; focus group.
Learning	Observations during the debriefing session; questionnaire: learning self-assessment immediately after the debriefing; multiple-choice test administered in school on the day after the visit; essay writing in school.

Observations were based on event-sampling, an approach whereby the observers record all instances of a particular behaviour during a specified time period. Each group of children was shadowed by two independent observers, who had received in-depth training on data-collection. The events of interest referred to problem-solving strategies, social interaction processes (including collaboration and competition), and interaction with the artefacts (mobile, map, and glossary). These events were recorded in an observation grid organized on the basis of mission and time. A number of pre-set options, derived from pilot testing, were displayed to simplify the observer's task.

Two questionnaires were developed for this study based on the QSA, an Italian questionnaire measuring learning motivation, strategies and behaviour [21]. The first questionnaire was administered individually at the archaeological park immediately after the game phase. It included 20 Likert-scale items, in the form of short statements regarding their game experience from the viewpoint of the following factors: collaboration, competition, motivation, fun, and challenge. Responses were modulated on a five point scale, ranging from 1 (strongly agree), to 5 (strongly disagree). In theme with the game experience, the questionnaire layout resembled a parchment with Roman numbers and a small Legionnaire icon. The second questionnaire was administered immediately after the debriefing to measure participants' evaluation on the discussion session and their opinions on how much they learnt during the game.

Learning was assessed on the day after the visit in school, via a multiple-choice test requiring the memory of facts, and knowledge application. The test was designed by researchers of Historia Ludens in collaboration with the school teachers.

Results

Results are reported in separate sections addressing behaviour, engagement, and learning. Reliability analysis was run for every questionnaire index reported, and yielded satisfactory values (α = > .80). The indexes were modulated on 5 points (1 = negative; 5 = positive). They all displayed severely skewed distribution; hence they were analysed by the Mann-Whitney U test, a nonparametric test equivalent to the t test. The Mann-Whitney test can establish whether two independent samples are from the same population. It is a relatively powerful non-parametric test since it uses the ranks of the cases.

Behaviour

The percentage of correct and wrong answers to each individual mission in the two game conditions is reported in Table 2. A strong difference in accuracy is evident. Specifically, the mobile condition was more prone to errors than the paper-based one, with a difference of some 20 percentage points. These errors were likely to occur with specific targets, such as the Civil Basilica and Thermae, which required more contextual knowledge for successful identification, as they shared several salient similarities with other targets.

Table 2. Accuracy in the two game conditions.

	Paper-based (N)		Mobile (N)	
	Right	Wrong	Right	Wrong
Furnace	5	\	5	1
Civil basilica	3	2	1	5
Temple	1	1	4	\
Foro Boario	4	\	3	1
Trajan Way	5	\	5	1
Store	5	\	2	\
Port	3	\	1	1
Epigraph	\	\	4	\
Forum	4	\	4	\
Thermae	2	\	\	4
Total	32	3	29	13
Percentage	91	9	69	31

This difference in performance cannot be explained by the trade-off between speed and accuracy, as participants playing the game in the paper-based condition completed the challenge faster (mean = 29.5 minutes; std dev = 6.43) than those in the mobile condition (mean = 38.5 minutes; std dev = 7.66). Rather, the difference can be explained by the sequential game procedure implemented in the cell phone condition, whereby participants had to solve one mission after the other. In fact, 4 out of 5 groups in the paper-based condition did not perform the missions following the order proposed in the challenge description, but rather preferred to choose their targets according to their locations or contextual knowledge. Another parallel strategy, commonly adopted in the paper-based condition, was to read several items in the glossary at the same time, making it possible to compare the details of similar targets. Once again, this behaviour was not possible in the mobile condition, as the 'Oracle' displayed only the glossary entry directly related to the active mission.

During the game, students could ask the game master for help in order to solve problems encountered in carrying out missions. No difference due to the game condition emerged. The paper-based group was helped by the game master an average of 3.2 times (std dev = 3.83), while the mobile group needed the game master's help an average of 3.5 times (std dev = 2.26).

The mobile group had little problems in using the cell phone, only in two cases at the start of the game did the technician need to intervene to explain how to use the phone. One paper-based condition group had difficulties in managing sheets, i.e. the wind complicated writing the answers. In both groups, students had some difficulties in reading the map, but the game master solved the problems. Another analysis addressed group dynamics during the game. In particular, we looked at leadership, defined as the participants' willingness to take charge of the game, contributing ideas and suggestions and allocating tasks to the other members. It was found that 50% of the participants who played the leader role in the mobile condition happened to be the one holding the cell phone, whereas no clear trends emerged in the paper-based condition.

The mobile groups were more competitive than the paper-based one. Usually, when they met they ignored each other and continued to carry out their own mission. They appeared very concentrated on their tasks and did not want to exchange any comments with their adversaries. The few questions they exchanged were aimed to get information that could be useful to them. Examples of such questions were: "*Have you found ****?*", "*Have you finished?*", "*What mission are you carrying out?*". In contrast, the paper-based groups were more talkative and often engaged in jokes and chit chat when they met. In general, however, winning appeared to be important to students, who often enquired about the other groups' performance during the game. We also witnessed a couple of attempts to cheat, where students tried to swap codes between different locations to make it impossible for others to win, or gave false answers to a direct enquiry.

Engagement

Overall, participants demonstrated with their behaviour and in the questionnaire that they were really enjoying playing the game. Participants score to the engagement index were very high (mean = 4.52; mode = 5). No differences between the conditions were found. To further analyse strengths and weakness of the game, we considered two open questions where participants reported the three best and the three worst features of the game. A total of 99 positive features were reported, and only 39 negative features. On the average participants in the mobile condition reported more positive features (mean per participant = 2.7) than the paper-based group (mean = 1.9). No differences in the number of negative features reported by the two groups emerged (mean =1).

Analysing the content of participants' self-reports it emerged a different trend in the two game conditions. The most frequently reported positive features in the mobile game addressed the artefacts used during the game, whereas in the paper-based condition participants referred most often to the archaeological park (Table 3). A total of 11 out of 19 references to artefacts in the mobile condition directly addressed the cell phone or some interface features, such as the Oracle and the 3D reconstructions. Overall, the 3D reconstructions were given a score of 4.3 on a 5 point scale. One of the students commented "*The mobile and the game are a winning combination*".

Table 3. Best features of the game.

	Paper-based N	Mobile N	Paper-based %	Mobile %
Collaboration	7	14	19	23
Fun	4	8	11	13
Challenge	2	6	5	10
Artefacts	4	19	11	31
Game master	2	2	5	3
Everything	1	2	3	3
Learning	6	8	16	13
Place	10	3	27	5
Other	1	0	3	0
Total	37	62	100	100

The collaborative nature of the game was indicated as another winning factor by both groups. Children enjoyed playing together and demonstrated a good team spirit all over the game. The learning potential of the game was another positive factor in both conditions. Students, especially those in the mobile condition, appreciated the difficulty of the game: they enjoyed because "*It was challenging*", as reported by a participant in a focus group.

As regards negative features, the trend of results is more homogeneous between the experimental conditions, although the mobile groups was more likely to complain about the difficulty of the game and the paper-based group was more likely to complain about the duration of the game, normally considered to be too brief (Table 4).

Table 4. Worst features of the game.

	Paper-based N	Mobile N	Paper-based %	Mobile %
Artefacts	3	3	16	15
Other	3	1	16	5
Complexity	6	11	32	55
Duration	5	2	26	10
Place	2	3	11	15
Total	19	20	100	100

Learning

During the debriefing, students were keen to engage in discussion and tended to respond with interest to the game master's questions; they also asked questions and proposed new topics of discussion. Overall we noticed a similar degree of participation in the two game conditions, although, on average, the debriefing after the mobile game lasted 10 minutes longer than the debriefing after the paper-based game. The difference is due to a longer time devoted to interact with the electronic map and to analyse the 3D reconstructions of the mission loci, which captured users' interest very much. Participants in the paper-based condition (who were shown a map and asked to indicate locations on it) were also very engaged in the activity, yet the digital augmentation of the process was highly appreciated by pupils, as explicitly indicated in both answers to the questionnaires and essays. In particular, participants demonstrated a strong appreciation of the virtual reconstruction of their group performance (showing the missions solved correctly and any errors on the digital map). Students also enjoyed the final prize-giving ceremony, indicating the 3 winner groups based on a combination of accuracy and speed in performing the game.

During the explanation enhanced by the virtual map, which was projected on the screen at the back of the game master, the 3D reconstructions were meant to be placed by an operator, following the children's suggestions on where to place it. In both groups, anyway, this behaviour was spontaneously modified by some children who quickly moved towards the computer and were left in charge of the operation. A common request from the pupils was to be able to hold a personal device to input on the map from their location. It was suggested that such a solution would permit a more democratic participation, allowing even shyer students to express opinions and cast their vote, protected by the anonymity of the situation. However, this solution was not universally accepted by all students, as some people wanted to stand out as individuals.

On average the students were very positive about the educational impact of the systems and they all agreed they had learned something (mean = 4.1; std dev = 0.66). No significant differences emerged in the group comparison. Participants' opinions were confirmed by an objective test. A total of 36 tests were returned for analysis (21 from the mobile condition; 15 from the paper-based one). On average, students answered 9 out of 11 questions correctly (std dev = 1.65). No significant differences between the game conditions emerged. The distributions are strikingly similar (mobile mean=8.8 (SE=.38); paper-based mean=9 (SE=.40)). The difference was tested by a t-test: $t(34)=-.437$, $p=.627$. Learning was correlated with measures of engagement ($r = .57$, $p < .001$) and motivation ($r= .37$, $p < .05$), which were collected after the game. In addition, it correlated highly with learning self-efficacy measured after the debriefing ($r = .65$, $p < .001$).

Discussion

Overall the study confirmed our expectations, derived from the theory of distributed cognition, that the two game conditions (paper-based and mobile) would give rise to different behavioural and social patterns. The most striking difference was in the game behaviour, because the sequential order imposed by Explore! degraded users problem-solving strategies. Mobile systems have a critical limitation in information presentation. Hence, when designing the system, we decided to propose to the players only those elements necessary to solve one mission at a time, i.e., the mission description and the related glossary item. The evaluation study revealed that in the paper-based condition, students changed the mission order, either firstly performing those missions they perceived as easier or according to a personal strategy. Moreover, students could read all items on the paper glossary at once, possibly getting more information for identifying the mission target. This could be one of the reasons why, in the paper-based condition, students completed the challenge in less time and with less errors.

We are now exploring new ways to give Explore!'s users more flexibility in problem-solving strategies and to provide more navigational hints. For example, we are implementing a context/task-aware help, whereby when the user activates the Oracle, the system provides appropriate indications based not only on the current mission, but also on the user position, provided by a GPS, and on task related knowledge, describing, for instance, similarities to other places. We have also started to place virtual sound sources at various locations at the site (e.g. noise from people at the market, crackling of the fire at the furnace, etc.) to increase the number of cues available for problem solving. Sound is also expected to enhance the overall user experience by helping users to become immersed in the role-play game.

The evaluation has also demonstrated that users enjoyed playing the game and, although we could not demonstrate the expected superiority of the mobile game by statistical comparison of questionnaire data, the introduction of the mobile appeared to be much appreciated. The use of the mobile was directly acknowledged as one of the best features of Explore!. We expect that, as we add to the interactive features of the mobile, we will also improve the user experience with Explore!.

Finally, our evaluation addressed learning outcomes of the two games conditions. No significant differences were found between them. This was an unexpected result, as we had hypothesised that the enhanced debriefing, allowing pupils to see 3D reconstructions and interactive maps, would have a positive effect on their learning. A possible explanation for this trend of results may be a ceiling effect, as the participants' performance in both conditions was very high. Yet, this finding needs to be weighted in view of the poorer performance, in terms of time and errors, achieved by the mobile condition on the field. Students in the mobile conditions performed worse during the game but somehow they managed to make up for it during the very final test. We believe that an instrumental aspect of this recovery lies in the debriefing. Seeing a realistic 3D reconstruction of the environment readdressed the students' performance and allowed them to achieve as much as their mates in the paper-based condition. Debriefing in the electronic version is superior also because, thanks to the collected logfiles, pupils can see their movements in the site and their overall performance, and so better understand the errors they made.

Both paper-based and mobile versions of the game rely too much on the game master's help. A further development of the mobile excursion-game will be to make it independent of the presence of the game master. This is not easy. We are thinking of augmenting the current help, so that it can give students more cues. Moreover, at the end of each mission, students will see the 3D reconstruction of the identified place, gaining immediate feedback. The debriefing is already designed to let history teachers accompanying the class to manage it. In this way, it will be easier to organize didactic visits since they have to be planned only by the school teachers, with no need for extra people to guide students during the game. Since families with young children are among the most common visitors to archaeological parks, our final goal is to adapt the game so that it can be played by families, thus engaging children and letting them have fun.

CONCLUSION AND IMPLICATIONS FOR M-LEARNING

Several authors agree that the slow progress of theories and methodologies about the overall user experience with computing technologies is due to a lack of empirical studies [12]. Mobile devices are carried by people everywhere and all the time. Insights into people's experience with such devices are better captured in field studies than in controlled experiments performed in more formal settings. One contribution of this paper is the methodologically sound approach adopted in the field study we have performed to evaluate Explore!, an m-learning system implementing a game to help middle school students to acquire historical notions while visiting archaeological parks. Another contribution is the novel m-learning technique adopted in Explore!, which is inspired by the excursion-game originally proposed by researchers in Teaching History.

The study was conducted at the archaeological park of Egnathia, in Southern Italy, and compared the experience of playing the game with and without technological support. This comparison evinced behavioural differences in the two versions of the game, showing a clear problem with the mobile version, as the information necessary to play the game was conveyed one at the time. This is a valuable result for designers, who need to be informed about behavioural limitations in mobile systems. The sequential approach to carry out the missions is typical of many mobile applications, where tasks need to be performed one at the time. The evaluation indicated that mobile games require more interaction freedom and, possibly, some context-dependent information to enhance the overall user experience.

The study also showed that, despite behavioural differences, there was no difference in learning in the two conditions (paper-based vs. mobile). This demonstrated that no distraction was generated in the students by the technology and proved the effectiveness of the electronic version of the excursion-game as a learning technique. As a consequence, e-learning can be regarded as equally valuable as traditional learning, provided that appropriate techniques are used, which are able to exploit the advantages of the technology and to engage and stimulate students.

The electronic version of the excursion-game technique presents various advantages that have motivated our efforts to design this m-learning system. First of all, Explore! permits the visualization of 3D reconstructions of historical monuments, only very little of which is still visible in the park. Not only do pupils see them during the game but they reflect on them much longer during the debriefing phase. This possibility was particularly appreciated by the pupils in the pilot study, who actually performed both games, the paper-based in a first visit for our contextual inquiry study [2], the mobile game during the pilot study. Their appreciation of the availability of the 3D reconstructions was explicitly stated in their essays.

As a further advantage, computing technology may give experts of Teaching History the possibility to easily adapt the game for different archaeological parks, without the assistance of a software engineer. This end-user development allows people who are not experts in Computer Science to modify or even create software artefacts [19]. This approach is exploited in Explore!. We are implementing a tool that allows an expert in Teaching History to create and manage the XML file without writing code. In Explore!, this file stores the historical information and determines the way it is presented on the cell phone. With this tool, the history expert can easily develop games for different sites.

ACKNOWLEDGEMENTS

Partial support for this research was provided by Italian MIUR (grant "CHAT"). We thank Historia Ludens for participating in the design of Explore!, the archaeologist Silvio Fioriello for providing the 3D models, and Francesca Montinaro, Nicla Bavaro, and the teachers and students of the school Michelangelo in Bari, Italy, for participating in the field studies.

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