Integrating traditional learning and games on large displays: an experimental study

C. Ardito, R. Lanzilotti, M.F. Costabile, G. Desolda

Dipartimento di Informatica, Università di Bari Aldo Moro, Italy
{carmelo.ardito, rosa.lanzilotti, maria.costabile, giuseppe.desolda}@uniba.it

ABSTRACT

Current information and communication technology (ICT) has the potential to bring further changes to education. New learning techniques must be identified to take advantage of recent technological tools, such as smartphones, multimodal interfaces, multi-touch displays, etc. Game-based techniques that capitalize on ICT have proven to be very valuable. This paper presents a study aimed at validating a new educational format, inspired by the Discovery Learning technique, which integrates educational games, designed to be played on large multi-touch displays, with other types of formal and informal learning. Six classes of a primary school were involved in the study. The results showed that the proposed educational format is effective and that games on these novel multi-touch systems engage pupils very much, stimulate their collaboration and help consolidating knowledge.

Keywords

Large multi-touch display, Educational game, Formal and informal learning, Discovery learning, Field study.

Introduction

The availability of new technologies, ranging from last generation mobile devices to gestural input, multimodal interfaces, multi-touch displays, etc., is bringing about changes in the field of education. Schools are under increasing political pressure to demonstrate that technologies actually improve student learning but assessments conducted on technology programs have not always yielded significantly improved student performances (Oviatt 2012). Our experience suggests that technological tools cannot replace the teacher, but they can certainly be considered a valid support for students in their learning paths (Costabile et al., 2008; Lanzilotti and Roselli, 2007). It is indispensable to define learning techniques that allow teachers to exploit technology to support students' acquisition of new knowledge. Games based on information and communication technologies have proven to provide a valid support for effective learning (Cabrera et al., 2005; Lanzilotti and Roselli, 2007; Rogers et al. 2005). An educational game creates a pleasant learning environment, in which students learn more easily and enjoyably. Games foster relational skills, encouraging young people to work in groups and collaborate to attain given objectives. Each student carries out the activities s/he feels most congenial and, by working together, they can solve clues or problems, overcoming difficulties thanks to their common efforts. Innovative technologies, like mobile devices, multimodal interfaces, multi-touch displays, etc., can make the game more engaging (Oviatt 2012).

This paper describes a study that shows how more traditional learning carried out at school may be integrated with educational games that employ advanced technology, namely large multi-touch displays. To perform this integration, a new educational format is proposed, which is inspired by the Discovery Learning technique defined by Bruner in his Constructivism theory (Bruner, 1990). Bruner defines learning as an active process in which new information goes through three different types of representation: *symbolic* (based on language), *active* (based on action), and *iconic* (based on images). The educational format indicates how to provide pupils information by integrating formal learning activities, as performed in traditional school settings, with more informal and technology-based learning activities, in order to facilitate knowledge acquisition and also consolidating it.

The study was conducted to validate the educational format and evaluate the use of the multi-touch technology in school. It enrolled 107 pupils of six fifth grade classes at a primary school in Bari, Italy. Results showed that the educational format was effective and all pupils enjoyed the experience. The system implementing the educational game proved to be very engaging, able to stimulate pupils to work in group and to favor inclusion. Inclusion refers to the involvement in the school activities of all students, regardless their possible disabilities, as those derived from the social, cultural and personal context of the student (Ianes, 2012). Indeed, even those pupils, who were usually timid in class, were very much involved and actively collaborated with their companions.

The paper is organized as follows. The next section reports related works on multi-touch technology applied to educational activities. The third section presents the educational format. The educational game implemented on a

large multi-touch display is described in the fourth section. Next, the field study and its results are reported. The paper concludes by discussing our findings and proposing directions for future research.

Related work

There is growing interest in investigating the use of multi-touch displays in different domains, thanks to their decreasing cost and increasing availability. Multi-touch displays have been used for gaming and entertainment (Tse et al., 2011), to support tourists (Jacucci et al., 2010; Marshall et al., 2011), etc. Researchers are now considering this new technology for educational purposes. We describe some examples in the following. Later in this section, we report three evaluation studies comparing the use of multi-touch displays with traditional paper and pencil and/or classic desktop applications.

One of the first examples of multi-touch technology applied to education was Read-it, a game-based application, designed to support the development of reading skills in children aged 5-7 years old (Sluis et al., 2004). The results of a pilot experiment, involving 15 pupils, clearly showed that pupils enjoyed playing the game and that the technology was not an obstacle to learning.

A few years later, Piper et al. presented SIDES (Shared Interfaces to Develop Effective Social Skills), a multi-player game that encouraged the use of cooperative skills by students in social group therapy (Piper et al., 2006). The results of two studies confirmed the authors' belief that cooperative games are an effective paradigm for teaching effective group work skills, and that tabletop technology provides promising tools facilitating cooperative gaming experiences for special needs populations.

Antle et al. developed an application, called Futura (The Sustainable Futures Game), whose aim is to explore the novel design space for multi-touch tabletop games (Antle, 2011). The learning goal was to help people improve their understanding of the sustainable development. Futura allowed players to see how and what their co-players were doing, providing opportunities for each player to learn from and help others. A study performed with hundreds of users of all ages during the 2010 Winter Olympics indicated that Futura was effective and enjoyable. Children and teenagers seemed to have more fun than adults, who seemed intimidated by their first round of play. No players had any difficulty understanding how to interact with the table.

Fu et al. proposed multi-touch technology to deliver an effective interface to navigate the unique features of 3D environments such as astrophysical simulations (Fu et al., 2010). To investigate people's behavior with this new educational approach, the authors performed a study with 16 participants, who liked very much the physical and intuitive interaction with a large display just using their hands.

To the best of our knowledge, the only example of multi-touch display set up vertically, as in our case, is "Us Hunters" a multi-user application that allows children, during their visit a museum, to experience and learn about the hunting strategies, which are depicted in a painting on the wall of a cave underneath the museum, dating 6000 B.C. (Kourakis and Pares, 2010). No formal evaluation had been yet performed. The children experience was observed by a guide expert in prehistoric art, who reported that, on the basis of comments and questions children asked after playing with Us Hunters, the application had great potential to be an effective tool in the learning process. A formal evaluation study was planned as future work.

Some researchers have compared learning through multi-touch technology with learning using a paper and pencil or a desktop. Piper and Hollan, for example, compared the results of presenting educational material on a tabletop display with presenting the same material using traditional paper handouts in a neuroscience class of 20 undergraduates at the University of California (Piper and Hollan, 2009). Results revealed that students studying the materials on the tabletop were able to overcome problems on their own and repeated activities more often than students studying with paper material. Moreover, greater playfulness and enjoyment were noticed.

Soro et al. compared observations of user behavior in pair programming tasks performed at a traditional desktop versus a multi-touch tabletop, studying 44 students of Computer Science or ICT professionals (Soro et al., 2011). Participants were asked to review 7 snippets through a simple interface, implemented with an identical look and feel for the desktop and the multi-touch table. Results showed that people performed better working at the multi-touch table, since it encouraged cooperation and helped people express their potential.

The study by AlAgha et al. aimed at understanding possible benefits of integrating multi-touch tabletop into classroom activities (AlAgha et al. 2010). They developed a system, called TablePortal, which allowed teachers to manage and monitor collaborative learning on students' multi-touch tables. The teacher used a separate table to communicate with the students' tables; in this way, teachers and students could work together on their multi-touch tables and collaborate on learning tasks. Observations in a real context showed an enhanced level of teacher's awareness, flexible monitoring, and a positive impact on social interactions in the classroom.
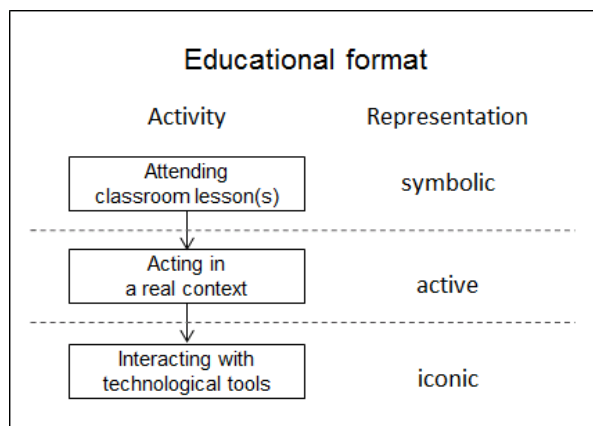
Our study, too, is focused on the integration of large multi-touch displays in school activities by proposing a format that includes other educational activities, as illustrated in the next section.

The educational format

The integration of formal and informal learning proposed in this paper is inspired by the Discovery Learning technique defined by Jerome Bruner in his pedagogical theory of Constructivism (Bruner, 1990). This theory supports the belief that learners construct new ideas or concepts based upon existing knowledge. Thus, the process of learning is active and involves transformation of information through three different types of representation, namely *symbolic, active*, and *iconic*, based on language, action, and images, respectively.

In the symbolic representation, information is mostly in the form of words, mathematical symbols and other symbolic systems (e.g. musical symbols). In the active representation, pupils learn by performing physical tasks, e.g. manipulating objects, working in the laboratory, visiting places like museums, monuments, etc. In the iconic representation, visual images are used to illustrate the concepts to be learned. More in general, an iconic representation can be visual, auditory, olfactory, or tactile.

According to Bruner, all three types of information representation are essential and important. Learners activate, perhaps unconsciously, one type of representation or another, and sometimes switch from one to another. For example, pupils learn to ride a bike not only by watching someone riding or reading a book of instructions, but they have to be active themselves. Bruner emphasizes the "discovery" in the learning process, because it stimulates learners to "construct" their knowledge and to detect correlations and regularity among the information they have acquired in one of the three types of representation, helping learners to identify possible transformation to be operated on the information in order to better understand it (Bruner, 1990).

Figure 1. Activities in the three phases of the educational format

The educational format we propose integrates formal learning (traditional classroom lessons) with more informal and technology-based learning, organizing learning activities in three phases (Figure 1). Pupils get new information by: 1) attending the lesson(s) by their teacher in the classroom (symbolic representation), 2) acting in a real context (active representation), and 3) interacting with technological tools to manipulate images (iconic representation). While the activity carried out in the symbolic phase is always the classroom lesson(s), those performed in the active and iconic phases change according to the topic to be learned and the technology used. For example, if the topic is natural science, in particular the naturalistic park habitat, pupils first attend lessons at school, then they explore the naturalistic park and lastly they interact with an educational system that allows them to manipulate concepts represented by images (e.g. a tree, a plant, etc.) showed on a digital screen.

In this paper, the educational format has been used to foster history learning and a keen interest in cultural heritage in primary school children aged 9-10 years old. Specifically, pupils learn about ancient Roman history by attending a lesson, in which their teacher provides basic notions on this topic (symbolic phase). After this, pupils learn during a school trip to an archaeological park of an ancient Roman city, or visiting a museum in which they watch how people used objects in the past. During the visit, the guide stimulates children to explore the site in order to discover signs of places and monuments of the ancient city. For example, the guide suggests: "Go in that direction and look for the rest

of a road paved with stone blocks. You may see signs left by the wheels of heavy carts". Finally, back at school, they interact with an application implemented on a large multi-touch display. This application, called History-Puzzle, is a game which proposes puzzles that pupils have to reassemble. The puzzles depict places or objects that pupils saw during the school trip.

A game on a large multi-touch display

The History-Puzzle game, considered in the third phase of the educational format, is implemented on a system with a large multi-touch display (Ardito et al., 2010). Such novel devices foster collaboration by allowing people to interact together at the same time. The display was set up in a vertical position to make it visible to other people standing nearby those currently interacting. We used a MultiTouch Ltd[1] 46-inch Full HD LCD display called cell. By mixing Rear Diffused Illumination and Led Light Plane technologies, this device is able to detect unlimited touch points. More cells can be linked to create greater screens. In our case, we used only one cell, not only for budget constraints but also because it was easier to transport and install. This device is very efficient in recognizing gestures, so even novice users can easily interact. Object manipulation is mediated by gestures performed with one or both hands (or some fingers). The main gestures are: *Move*, to move an object on the screen, which can be done with one hand just by touching the video; *Scale*, to change the size of an object, done with the index fingers of both hands, by stretching or narrowing two corners of the object; *Rotate*, to rotate an object, again using the index fingers of both hands. History-Puzzle has been developed in Java, with the open source MT4J (Multitouch for Java) development platform[2]. The TUIO protocol[3] has been adopted to allow communication between the touch-capture system and the software application.

History-Puzzle is designed to be played by children interacting with a multi-touch display installed in a school laboratory, in an indoor space of an archaeological park, or in a museum. It is named History-Puzzle because groups of pupils collaborate to reassemble puzzles to discover elements of interest at an historical site. In the game played after a visit to the archaeological park of Egnathia, in Southern Italy, the puzzle images are significant places in this ancient Roman city, e.g. the Civil Basilica (the Law Court), the Trajan Way (the main road from Rome traversing Egnathia), the Foro Boario (the animal market square), the Kiln (oven for cooking terracotta vases). For example, after a player selects a puzzle, such as the Trajan Way (Via Traiana in Italian), a screen like the one shown in Figure 2 appears. The figure to be discovered by solving the puzzle is at the center of the screen. The nine square tiles covering the figure contain incomplete sentences reporting historical notions about the selected place. For each tile, the players choose the rest of the sentence from the tiles displayed on the left and right sides of the puzzle and drag it onto the tile in the figure.

Figure 2. The screen to start solving the puzzle "Via Traiana"

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[1] http://multitouch.fi/.

[2] http://www.mt4j.org/.

[3] http://www.tuio.org/.

In the example in Figure 2, the sentence "Collegava Benevento a …" ("It connected Benevento to…" in English) is associated to the town name "… Brindisi". If the selected association is correct, the tile will reveal one ninth of the 3D reconstruction of the original place. Figure 3 shows what it looks like when the player has discovered 7/9 of the image.

Figure 3. Seven parts of "Via Traiana" have been discovered

Some tricks are inserted to make the game more challenging and intriguing: 1) more than nine tiles are shown outside the puzzle: these additional tiles report false answers or answers that do not match any of the nine incomplete sentences displayed; 2) the positions of the tiles with incomplete sentences and those with completing sentences are randomly reassigned each time the puzzle is run; 3) sentences are randomly chosen from a file containing about 30 sentences for each puzzle. When the nine sentences have been completed and the whole image is displayed, a new game screen is shown. It proposes different multimedia contents: a papyrus reporting all the puzzle sentences, a short video showing the 3D reconstruction of the place, photos of the place, the half-section plan of a building (Figure 4).

Figure 4. Multimedia contents associated to the "Via Traiana" puzzle

The system also reproduces sounds associated to the place, various noises of typical activities carried out when the civilization of Egnathia was alive. In the case of the Trajan Way, carts and horses running are heard. Finally, the system returns to a screen showing the map of the park (Figure 5). The number "44", displayed on the Trajan Way, indicates how many points the group gained for solving that puzzle. This score is computed by summing the number of correct associations and subtracting the number of wrong ones. A score of 5 points is awarded if the sentence is correctly associated, while the score is reduced of 2 points every time children move a tile on a wrong one. This

score mechanism stimulates children to reflect upon their actions and leads them to discuss together on the tiles they have to associate.

Figure 5. Map of the archaeological park showing the available puzzles

Field study

A field study conducted during November-December 2011 at a primary school had three goals: 1) to investigate the pupils' experience in the interaction with multi-touch displays in a real context; 2) to evaluate the effect of multi-touch technology as a means of consolidating knowledge; 3) to analyze the effectiveness of the proposed educational format.

Participants and Design

The study involved six fifth grade classes at the primary school "Clementina Perone" in Bari, Italy. A total of 107 pupils (55 girls, average age 10) participated in the evaluation as part of their school activities. For goal 2), a subset of 53 pupils (hereafter denominated the *multi-touch group*) belonging to three classes answered a true/false test twice: immediately before and after interacting with History-Puzzle. For goal 3), all pupils answered the same test only at the end of the educational experience.

Procedure

The study lasted four weeks and consisted of three phases: *symbolic*, *active* and *iconic*. During the first phase, participants attended a 2 hour lesson in which the class teacher presented basic notions about ancient Roman history focusing on Egnathia, a city which was active from the IV century BC. In the second week, the active phase was carried out through a school trip to Egnathia, in which they visited the archaeological park of Egnathia and the museum; a professional guide accompanied them in the park, helping pupils to identify meaningful places of the ancient Roman city, and later in the museum, where pupils saw how the ancient people used objects in their daily life.

During the third week, in the iconic phase, the six classes took turns, in groups of 4/5 pupils from the same class, to go to the school laboratory where the multi-touch display was installed, and play with History-Puzzle. All the other pupils stayed in class doing other activities unrelated to Roman history. This was because the technical and human resources were sufficient to observe only one group playing the game at a time. Each group had a total of 15 minutes to play with the multi-touch display and solve three puzzles; they could freely decide which strategies to adopt to reassemble puzzles. After the whole class had interacted with the display, they answered a true/false test in the classroom to measure the acquired knowledge. Then, the procedure was repeated with pupils of another class. Three

classes were observed on one day and the other three classes the day after; the multi-touch group answered the true/false test both before and after playing with History-Puzzle.

Pupils were observed by two research assistants, who noted down the main events and provided help during the interaction when explicitly requested. Two cameras were used for videotaping. Camera 1 was installed on a tripod placed to one side about two meters away from the system to film hand movements on the screen. Camera 2 was placed on top of the display to film the children's faces while they interacted with the system.

During the fourth week, a focus group was held in each class, moderated by the teachers. This served to gather information on the overall experience, starting from the lesson about Egnathia, passing through the school trip and finishing with the game on the multi-touch display. The six focus groups were video-taped and a research assistant noted down the pupils' most important observations.

Two months after the study, interviews to the four teachers of the classes involved in the study were performed. The aim was to get their views on the educational format by also considering the possible pupils reactions during the period following the study. The interviews were registered.

Results

The value of the proposed educational format, which integrates informal learning based on the use of a digital game, does not lie only in assessing how much pupils learned, but how they learned, i.e. how much they were engaged in what they were doing, if they liked it, if they enjoyed collaborating. Thus, in our study, we collected and analyzed a considerable amount of qualitative data. Quantitative data were gathered through true/false tests that have been administered to address learning; they were complemented with comments provided by the teachers during individual interviews.

In this section, we first illustrate results about learning then, we report the data gathered during observations of the pupils interacting with the History-Puzzle application, and their comments during the focus groups, in order to evaluate the overall pupils' experience. Such data are presented in three parts, addressing pupils' behavior, their performance and their own perception, respectively.

Three researchers analyzed a total of 5 hours, 46 minutes and 11 seconds of videos of 22 groups interacting with History-Puzzle. Researchers independently double-checked some 50% of the material. If the inter-rater agreement was less than 70%, the researchers discussed the differences and reached a mutual agreement. Reliability was high (agreement over 85%) for all the variables reported in this paper.

Learning

An initial quantitative analysis on the test administered to the pupils was performed to measure the knowledge acquired. The true/false test included 27 questions addressing different aspects of everyday life in Egnathia, illustrated by teachers during the lessons, repeated by the guide during the trip, and seen again on the multi-touch display. This test was administered to all pupils after the use of History-Puzzle to measure the effectiveness of the educational format. The multi-touch group did this test twice (before and after using the multi-touch display). A learning score was obtained for each assessment phase, summing the number of correct answers at each test and converting these results to decimals. On average, all participants obtained a learning score of 7.12 (SD = 1.02). The two learning scores of the multi-touch group were analyzed by t-test, that revealed a significant effect $(t(99) = 2.83$ p $< .005)$. On average, participants answered 17.2 items correctly prior to the multi-touch interaction and 19.24 items after the interaction.

In the interviews performed to the four teachers, it emerged that, in their opinions, the educational format facilitated pupils to acquire contents that were presented in the different phases. Teachers said that there is evidence that the knowledge gained from the game remained very much impressed. They noticed that, during school activities performed some weeks after the study, in which there was the occasion to discuss concepts of the ancient Roman life, pupils often made reference to their experience with History-Puzzle and with the visit to the archaeological park. For example, during a visit to the ancient area of Bari, a month after playing the game, looking at the rest of the Trajan Way in Bari, some pupils explained: *"Oh, it is the same road we saw at Egnathia and on the multi-touch display!".* Indeed, teachers' experience shows that children of this age learn a lot by observing images. In addition, the use of a multi-touch display involved children at sensory level by allowing them to touch with their hands images and to interact with them.

All teachers highlighted that pupils felt protagonists, especially during the visit and the game. A major positive result was about pupils' inclusion (Ianes, 2012): those pupils, who in class seem apathetic, not motivated and tend to distract, actively participated in the game, provided appropriate answers and contributed to the group activities with enthusiasm.

Teachers also noticed that, when children interacted with the multi-touch display, they made spontaneous reflections and self-assessments. In particular, three teachers reported that they often heard the children explaining very proudly *"Yes, I answered right here!"* or saying sadly: *"No, the answer I gave was wrong!"*. Another important aspect that teachers reported was collaboration. Generally, in laboratory activities, children work in pairs and sometimes individually. With the multi-touch display, children enjoyed work in larger groups and interacting with their peers.

Behavior

In total, the 22 groups employed 3 hours, 58 minutes and 19 seconds to solve the three puzzles; on average, a group spent 10 minutes and 50 seconds to reassemble the three puzzles. The remaining time was used by participants to: decide which puzzle to solve, watch the multimedia contents available on the display after each puzzle, decide on the name their group and see their scores.

During the study it was observed that multi-touch display stimulates collaboration encouraging group activities. In fact, participants generally collaborated a lot to reassemble the puzzles. Only in 8 out of the 22 groups did each pupil in a group work alone to compose parts of a puzzle. Different strategies were used: a) some groups divided the tiles according to the members' position in front of the display, as illustrated by the following excerpts: *"You do that part because you're on the right and we'll do this one"*; b) other groups established impartial rules: *"Let's take turns, one tile each"*; c) other groups decided that the puzzle should be built by each member who proposed a possible right answer: *"You said it so you do it"*.

The groups mainly stayed united and collaborated to reassemble the puzzle. If one member tended to draw back the others encouraged her/him to take a more active part. This cohesion was particularly evident when they got into difficulties, as demonstrated by the following pupil's exclamation: *"United we stand"* (see Figure 6).

Figure 6. Two pupils moving a tile together

In 13 out of 22 groups, there was no dispute (Table 1). In 5 groups the pupils disagreed only once, in 2 groups twice, 4 times in one group, and 6 times in another group. This last group quarreled about the use of the display because one member wanted to hog the whole game.

Table 1: Disputes while playing the game

Dispute situations	N. of groups
Never	13
Once	5
Twice	2
4 times	1
6 times	1

Analysis of the group dynamics during the game addressed the leader role, which is negative in this case. In fact, a leader role means that one pupil tends to impose her/his will on the others, dictating which tile should be moved and why. This was often accompanied by dominant gestures like blocking another pupil's hands to prevent her/him from touching the tiles. Only in 36% of the sample did a pupil attempt to play a leader role. These members were not well accepted by the rest of the group, who all wanted to take an active part in solving the puzzle, and rebellion and confusion ensued: *"Michele, stop, you've already done two! Let us play too!"*.

Competition is an aspect that often emerges in gameplay. A reasonable degree of competition is considered positive to motivate and stimulate players to do their best. In our study, intra-group competition did not really occur because the pupils in the group mainly collaborated to carry out the game. Each group appeared interested in doing better than the other groups and they all checked their final scores against those of the other groups on the overall classification the system shows on request. Moreover, in 11 out of the 22 groups there was at least one explicit competition episode (Table 2), that emerged when one or more members of the group insisted that they needed to get as high a score as possible (e.g., a child said: *"Let's try not to make a mistake so as to get as many points as possible"*).

Table 2: Number of events in which competition is evident in the group

N. of competition events	N. of groups
0	11
1	7
2	3
5	1

The multimedia contents available at the end of each puzzle composition were generally not found interesting because the groups wanted to go on to solve the next puzzle. Table 3 shows the time each group spent watching such contents. It was assumed that 15 groups were not very interested because they observed the contents for only 1-4 seconds. The 5 groups that spent 5-10 seconds watched the initial part of the video and some photos, whereas the last 3 groups actively interacted with this multimedia content, and had fun zooming in and out, and rotating it.

Table 3: Time the groups spent watching multimedia contents

Time (seconds)	N. of groups
1-4	15
5-10	4
11-22	3

A lot of pupils enjoyed doing the puzzle; this could also be seen by the fact that they accompanied the movement of the tile with their whole bodies: they knelt while they moved the tile down or leaned over to the right or left as they moved the tile in that direction.

Performance

The first puzzle was used to understand game and interaction mechanisms, and to get organized, and then they were able to solve the next puzzles more rapidly (Table 4). Although the three puzzles had the same difficulty, pupils employed about 29% of the total time to reassemble the first puzzle, decreasing to 24% for the second puzzle and only 17% of the time for the last puzzle.

Table 4: Percentage of total time pupils employed to perform game activities

Game activity	Time (%)
Solving the first puzzle	29
Solving the second puzzle	24
Solving the third puzzle	17
Observing multimedia contents about puzzles	5
Other	25
	100

Pupils had no problems in understanding the game mechanisms, but they encountered some problems of a technological nature (Table 5). In fact, the screen was less sensitive at the margins and in a central strip about two centimetres wide, making interaction with the object more difficult at these points. In these cases, too, pupils collaborated to solve the technological problem: if one of them had understood how to overcome the problem, she/he suggested the solution: *"Drag it upward otherwise it thinks we want to put it there and won't go, indicating an error"*. Unfortunately, only 2 out of the 22 groups did not encounter a technological problem but 12 of these groups had only one problem that they succeeded in solving alone (Table 5).

At the beginning of their interaction, if children had to associate a side tile with a puzzle tile located on the opposite side of the screen, their first attempt was to move the tile across the puzzle area. This was interpreted by the system as the association of the tile with the first one that was overlapped, generating a mistake. However, children soon understood that they had to reach the right tile by going around the puzzle area.

Table 5: Number of technological problems arising with the game

N. of problems	N. of groups
0	2
1	12
2	4
3-5	4

Perception

In previous studies, the questionnaire was used to gather data on pupils' perception of the experience [8]. We found out that pupils were not able to clearly express their opinions. Thus, for this study we decided to perform a focus group in class to collect pupils' comments on the overall experience.

The focus group data showed that participants tended to share knowledge acquired during the game, as well as about how to interact with the new technology. The participants explicitly declared that they greatly enjoyed the group experience they had with History-Puzzle, because it allowed each of them to remember, reflect and share knowledge with their peers. They said that the sentences they had to associate during the game were very useful to remember concepts learnt during classroom lessons and to better understand some aspects they had missed during the visit because sometimes they were distracted. They pointed out that they would prefer even a larger display to permit more groups to play together, rather than having to take turns.

Among the three types of information representation, they particularly appreciated the visit to Egnathia, because it allowed them to see what they had learned with the teachers, and also to admire cultural and archaeological heritage located in their territory, stimulating their powers of imagination and observation. In fact, they said things like: "*It's like really living in this place", "I felt like an explorer!", "I imagined the people of the time riding down the Trajan Way in carts", "No, I imagined people working in the mills"*.

Discussion

The study reported in this paper was focused on three main issues: 1) investigating pupils' experience in the interaction with multi-touch displays in a real context, 2) evaluating the effect of multi-touch technology as a means of consolidating knowledge, 3) analyzing the effectiveness of the proposed educational format.

As to the first question, the study demonstrated that pupils enjoyed the game and were actively engaged; they liked playing in groups and would have liked to play longer and with more companions. After the first puzzle, pupils often

decided to divide the tasks among themselves so as to solve the problems faster. Multi-touch technology is very promising in facilitating collaborative experiences, as also indicated in (Piper et al., 2006). In fact, collaboration among pupils was the most important aspect observed during the study. The groups tended to work together, helping others who got into difficulties, suggesting solutions to problems emerging during the play, and exchanging information among them. Even if in some cases one pupil tried to take over the game and become the leader, this annoyed the other players because they preferred to work together. The study also revealed minimal competition among groups that preferred to go on working on the puzzle rather than watching photos or reading information given them after each puzzle. The game was very engaging, as shown by the fact that children moved their whole bodies in time with movements of the tiles.

As regards the second question, the study highlighted the value of the multi-touch technology as an important means to support knowledge consolidation. Pupils gave more correct answers to the true/false test performed after the multi-touch, confirming the results reported in (Sluis et al., 2004) that technology is not an obstacle for pupils but, on the contrary, can be effective to support learning processes. This result has been reported also by the teachers that were interviewed. The major surprise for the teacher was to discover that also pupils that in class are less motivated, during the interaction with the multi-touch display actively participated providing appropriate answers.

Finally, the data gathered during the focus group, the true/false test and the teachers' comments provided further evidence that the three types of information representation (symbolic, active and iconic) are essential and important, and each reinforces the others. The symbolic representation was useful to introduce the new concepts. The active representation stimulated children's imagination and observation, and engendered a strong interest in history by allowing them to see and hear what life was like in ancient times. Finally, the iconic representation using multi-touch technology was useful not only in engaging pupils' interest and enthusiasm while reinforcing the knowledge acquired, but also in stimulating collaboration and group work. The learning triad was successful as shown by the final assessment tests revealing that, in general, pupils reached a good knowledge level.

Conclusion

The introduction of ICT in education has encouraged the expression of information in different representations, modalities, and linguistic codes to stimulate ideas, clarity of thought, and improved performance in educational activities (Oviatt, 2012). This is especially evident when recent technological tools, like smart phones, multi-touch displays, etc. are used, but new learning techniques to fully exploit all these technological potentialities need to be defined.

In this paper, we showed that educational games using multi-touch displays are able to promote pupil learning, especially when games are integrated with other informal learning, such as a school trip, as well as traditional school lessons. This integration is proposed through an educational format that refers to the Discovery Learning technique, defined by Bruner (Bruner, 1990). According to this format, pupils learn through three different phases: 1) attending the lesson(s) by their teacher in the classroom (symbolic phase), 2) acting in a real context (active phase), and, finally, 3) interacting with technological tools (iconic phase), like the educational game on a large multi-touch display described in this paper.

Results of the field study showed that pupils were actively engaged in all the educational activities, indicating that the proposed educational format is effective and that applications on the multi-touch display can be a valid means for consolidating knowledge.

Bruner's theory does not indicate any particular sequence in using the different representations for providing information. In designing the educational format, we decided to implement the technology-based iconic representation in the third phase. This decision was taken after discussions with teachers, who prefer to use technological tools to deepen knowledge and practice new concepts which have previously been introduced in formal lessons. Future work will include further studies to investigate different sequencing of the three phases in the educational format.

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