Multi-touch Rocks: User Experience Metrics for a Multi-user Game on a Multi-touch Table

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ABSTRACT
More than 50.000 petroglyphs are engraved in rock panels on the flanks of the UNESCO world heritage site Valcamonica (Northern Italy). The engravings are not always visible and are often on steep slopes on which it is forbidden to walk for conservation reasons. To overcome these problems, and to be able to transfer the rock art experience to other places, we designed a collaborative computer game for a multi-touch tabletop display. The game contains the image of a full rock panel and several mini-games to be played on the panel. This paper describes the game design as well as the interface and interaction design and a large-scale user experience test. We propose novel user experience metrics for multi-user multi-touch tables. We used a public event for a user experience test to validate these metrics. The test achieved largely good results.

INTRODUCTION
A small valley in the Lombard Alps of northern Italy contains precious rock art. Around 5000 years ago members of the Camunian tribe started to use quartzite hammers to smash images out of the flanks of the Valcamonica. The images are spread over many rocks around the valley. Some of the rocks are easily accessible, but others are hidden under a thousand year old layer of earth and moss. The rock art in the Valcamonica is a UNESCO world heritage site and has resisted the extremes of summer and winter since the Copper Age. The images illustrate houses, animals, warriors, tools and much more. Altogether over 50.000 "Pitoti" (a local dialect word for the small puppet) are engraved into the rocks [4].

To facilitate a gain of knowledge about the Pitoti for the general public we create a collaborative educational computer game for public spaces (e.g. museums). It allows the rock art to come to the audience, since the rock cannot be transported. Furthermore, it allows the audience to interact with the Pitoti, which are not always visible because they are often on steep slopes on which it is forbidden to walk for conservation reasons. Finally the game allows the visitors to explore the interactions between the engravings by playing the games. The interaction design of the game is adapted to our target group – students aged between 10 and 18 years. We aim at an exciting experience for young visitors while exploring a rock panel and playing the mini-games. We aim to achieve this by helping the audience to turn prehistoric spaces into interesting places, in which the Pitoti act out past events. The basis for our game is an image of a 15x10m^2 rock panel in the Valcamonica named *Seradina 12*. To get a whole image of the rock panel we acquired several hundred single digital images of the rock. Figure 1 shows a part of the rock panel and its surroundings. Figure 2 depicts a detail. The complete image with a size of three gigapixels has been stitched of the more than two hundred single images. The game will be placed in a museum. Computers in public space have to be easily usable and robust. Therefore, we use a multi-touch tabletop display for the implementation of our game. Tabletops have been widely used for over a decade now. We expect a continuing increase in usage of these systems, as new technologies (e.g. Microsoft Surface 2) allow less expensive multi-touch setups.

In this paper, we describe the game design, the user interface of our game and the metrics we defined and used in our second user test. We performed a first user test several months ago [14]. This first test aimed at the evaluation of the usability of our system and yielded valuable results about the effectiveness and efficiency of the user interface. Now, for our second test, we focus on measuring the user experience. We extend our test to additionally evaluate user satisfaction, expectation and learnability of our game.

Our contribution is the proposed evaluation methodology for multi-user multi-touch tables and a user experience test to evaluate the methodology. This paper is organized as follows: First, we summarize related work in the following section. The next section contains the description of our game and its user interface. In the subsequent two sections, we describe the user experience test of our game and its results. Finally, we draw conclusions and line out future work.

RELATED WORK
We consider related work in the fields of game design, interface and interaction design and usability testing on multi-touch devices.

Figure 1. A part of the rock panel we use (Serradina I rock 12) and its surroundings. Pitoti are in the lower right part of the image.

Figure 2. A detail of the rock panel we use (Seradina I rock 12) showing a Pitoti.

Since touch devices such as smart phones and tabletop displays have become very popular, the number of applications for those increases steadily. The use of touch displays in public institutions (e.g. museums) is a common practice. Geller [5] describes that interactive displays in exhibitions encourage a collaborative atmosphere and facilitate a face-to-face experience that visitors get by working around a table with other visitors. As for game design, the designer has to distinguish between a game design for a nonpublic settings and a game design for public space. A game for home use can be more complex, because the user has more time to learn something about the game. A game design for a public setting should be simple to understand and allow the player to enter the game without previous studying of rules. Cao et al. [1] state five requirements that the game design for a public game should fulfill: a) casual and lightweight; b) simple to understand and operate; c) suitable for various populations; d) ad-hoc joining and leaving and e) encouraging group play and communication. Schild and Masuch [13] describe the creation of the multi-touch game "magic garden". This game is made for a large tabletop display that allows ad-hoc play in public places. The game includes self-contained mini-games put into one game scenario.

Interface and interaction design aim at efficiency and simplicity of the human computer interface. Nielsen [10] states, that a reduction of functionality in the interface as well as the product decreases the cognitive workload for the user. Hence, the user has more cognitive capacity for playing and learning. Saffer [11] proposes seven gestures for touch screens: tap, drag/slide, flick, nudge, pinch, spread and hold. Hinrichs et al. [6] show that the choice and use of multi-touch gestures are influenced by general preferences, interaction context and social context.

The evaluation of the interface/interaction design and user experience (UX) is an important and necessary step in the user centered design approach. Tullis and Albert [15] define that user experience *"... takes a broader view, looking at the individual's entire interaction with the thing, as well as the thoughts, feelings, and perceptions that result from that interaction"*.

Bargas-Avila and Hornbæk [7] review how empirical research on UX is conducted. Collecting data on UX offers new ways of understanding and studying the quality-in-use of interactive products. The data can be qualitative or quantitative [9]. For the development process it is important, that the right usability metrics are defined. Tullis and Albert define metrics as *"... a way of measuring or evaluating a particular phenomenon or thing"* [15]. Usability metrics are very important for testing and evaluating interactive systems. We know metrics from our daily live. For example when we buy a car, there are some cars with more horsepower (hp) than others. And we can say, the more horsepower a car has, the more speed it gets. So we can say a car is faster because we can measure the speed and based on the horsepower we are able to compare. The usability metrics for UX tests are no different. We can measure the task success, time-on-task, errors, efficiency, learnability, user satisfaction, etc [15]. However, all usability metrics must be measurable, quantifiable and observable [15]. The measurements are various. Correia et al. [2] use a logging mechanism to record interactions on a multi-touch tabletop in a museum. Hinrichs et al. [6] describe their findings from a field study with analyzing

Figure 3. The Rosa Camuna marks the entry point to a mini-game.

video recordings. They want to find out how visitors interact with a large interactive table exhibit using multi-touch gestures. Khaled et al. [8] report the observation of multi-touch collaborative game play.

GAME CONCEPT

The starting point of our application is a full-scale image of the rock panel named Seradina 12. Several types of mini-games are embedded in this complete scenario. The entry points to the mini-games are marked by the Rosa Camuna (see Figure 3), one of the most significant petroglyphs of the Camunian tribe. Players can explore the three gigapixel image of the panel by three gestures: spread (zoom in), pinch (zoom out) and drag (pan). We make use of those simple gestures because these are most common and intuitive. The zoom levels range from a detailed view at 200% of the real size of the stone to a total view of the rock panel. The user can explore the rock panel and zoom and navigate to interesting Pitotis without touching the real stone. The game design of the mini-games is adapted to our target group, 10-18 years old students. There are four mini-games, which are dealing with the environment of the Camuni.

- Put the clothes of a hunter and a warrior back on (two mini-games)
- Catch the runaway oxen
- Put the deer back together

Put the clothes on

This mini-game is a puzzle game (see Figure 4), in which players move, scale and rotate scattered parts of a warrior/hunter together. The elements are smaller or larger than the original and/or have to be rotated to be in the right position.

Catch the runaway oxen

"Oh no, the oxen run away!" The aim of this game is to catch the oxen and bring them back behind the fence (see Figure 5). With the help of four dogs, the players can drag a path. A dog will follow this path. Through an implemented gravitation field around both animals, the oxen run away from the dogs. With the right drawing of paths and the subsequent movement from the oxen, the players can herd them back into the fence.

Put the deer back together

This mini-game is equal to the "Put the clothes on" game. The players put the elements of a deer back together again (see Figure 6).

Figure 4. One of the mini-games: "Put the clothes of the hunter on".

Figure 5. The mini-game "Catch the run away horses".

Figure 6. The elements have to be rotated or scaled to be in the right position.

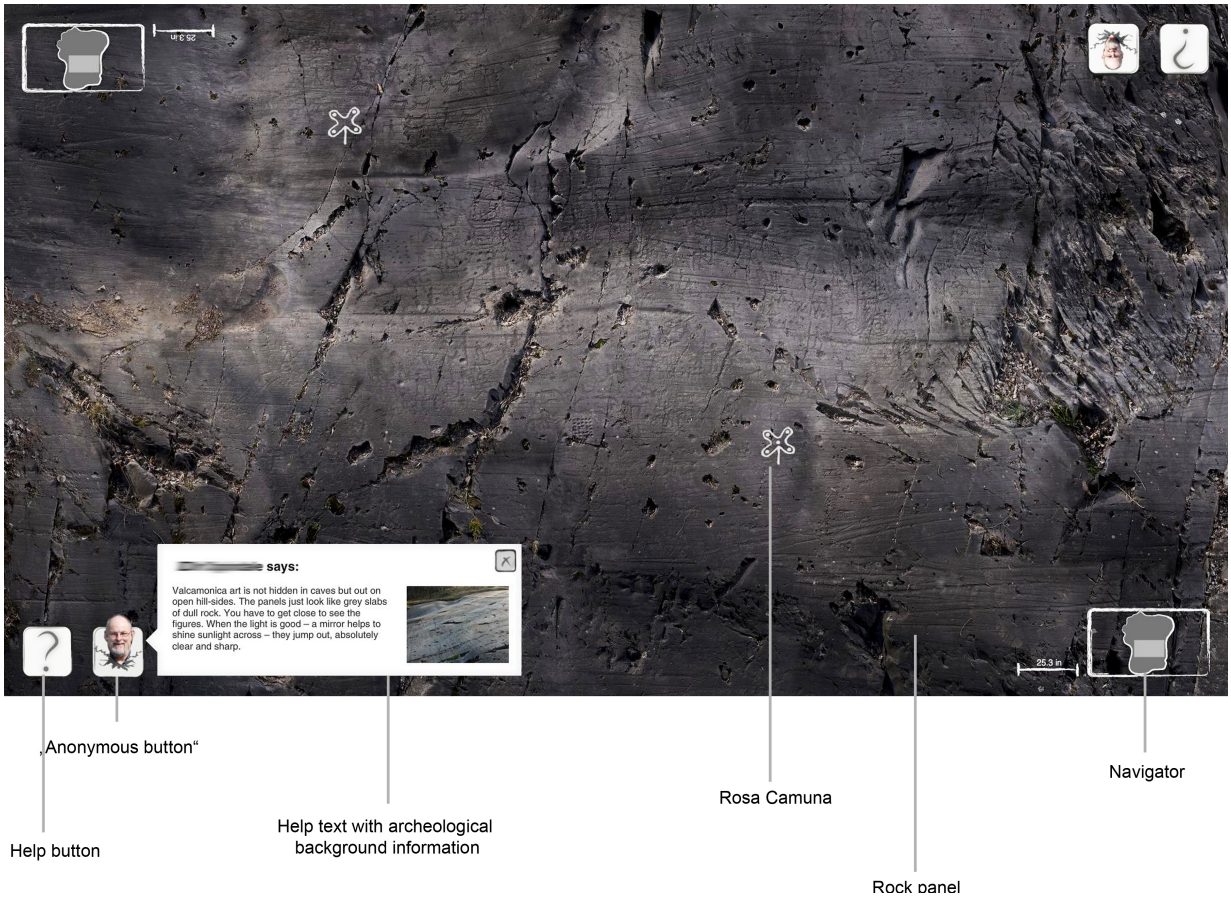

Figure 7. Panel view with open "Anonymous button".

INTERFACE AND INTERACTION DESIGN

It is important that the mini-games are simple to understand and operate. All mini-games can be played by one player, or by a cooperative team of players. The players should have an entertaining interaction and gather new information about the Camuni and their life. The players can enter and leave the game at any time and the games can be played in any order. Figure 7 shows the panel view with the buttons, the Rosa Camuna, the navigator and the open help text of the *Anonymous button*. Our interaction and game design is based on an ad-hoc collaborative multi-touch game play and fulfills the five requirements that the game design for a public game should have: a) casual and lightweight; b) simple to understand and operate; c) suitable for various populations; d) ad-hoc joining and leaving and e) encouraging group play and communication [1]. Therefore, we have to involve the players quickly without learning any difficult gestures or previous knowledge about the Pitoti. We reduce the number of utilized gestures as much as possible and finally utilize five gestures: tap, drag, pinch, spread and rotate.

If the player wants some background information about the archaeological point of view, the archeologist *Anonymous* explains it. A tap on the *Anonymous button* opens a textbox with all the information directly above the button (see Figure 7). Besides the archaeological information, general help can be accessed at any game state and on the complete scenario. The *General Help Button* explains all kinds of gestures, which can be used in the current view. The explanation of the gestures is supported by short and easy to understand animations. If nobody is interacting with the table for a certain amount of time, an autopilot starts. The autopilot is an animated video, which shows interesting areas on the rock panel with many Pitoti on it. An image of a hand which is panning should stimulate the users to touch and interact with the table.

USER EXPERIENCE TEST

Test plan and setting

The first test, which was focused on usability, was conducted in a laboratory setting with three groups of students aged 12-14 years. At this point, we had implemented the rock panel with its zoom and pan functionality and one mini game. The first test gave valuable feedback about the effectiveness and efficiency of the user interface. We describe the test setting and the test in [14]. After this test, we implemented some changes that the results of the test suggested. Subsequently, we implemented more functionality and mini games. For the second test, which aims at user experience, our system is ready with full functionality.

The UX test is focused on effectiveness, efficiency, learnability and user satisfaction. We plan the UX test

Figure 8. The public event provides an opportunity to test our system with many people.

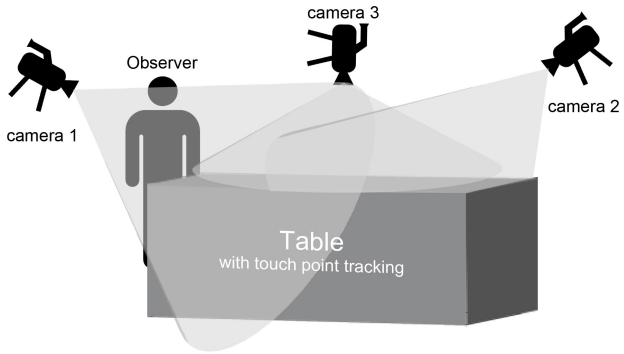

Figure 9. The setup of the test. Three video cameras, a observer and the tracking mechanism.

because we want to improve our developed system further. There are five characteristics of every UX test: *1) improve the usability of a product; 2) the participants should represent real users; 3) participants should do real tasks; 4) observe and record what participants do and say; 5) analyze the data, diagnose the real problems and recommend changes to fix those problems [3]*. We planed and focused our UX test based on these characteristics.

The system was exhibited at a public event dealing with the Pitoti. The event was a good test setting for our UX test because the surrounding was similar to the museum location where our system will be exhibited.

The visitors of the event included but were not limited to our primary target group of the multi-touch application. Many families, elder persons, groups of kids, couples and singles were working around the table with other visitors (in total ~50% of them male and ~50% of them female). A collaborative and entertaining interaction proceeded (see Figure 8).

We placed the multi-touch table with sufficient space for larger groups around the multi-touch table, equivalent to the situation in the museum where the table will be exhibited. Our UX data collection methods are: questionnaires, user observation, touch point tracking and video recording. The reason for four different data methods was to get as much information as possible about our system and the interaction with it. The visitors did not get any briefing about the type of interface or of the software on the multi-touch table.

Our hardware setup consists of three video cameras and one photo camera (see Figure 9). Two video cameras were focused on the faces of the players and the surrounding area to record the feedback and the mood of the visitors. The third camera was focused on the surface of the multi-touch table. We synchronized the three video recordings to merge them together to get an informative evaluation after the UX test. With the photo camera, we took some pictures of the players while they were around our table. During the UX test, we took notes of interesting and significant occurrences. To measure the UX, we defined UX metrics. Furthermore, we handed out self-developed questionnaires to the players after they had visited our table. In order to measure how the interface was used, we developed a tracking mechanism to record the spatial and temporal locations of all touch points. We tracked the whole eight hours of the UX test.

The interactive table is equipped with a 55 inch touch frame from PQ Labs. It can handle 32 simultaneous touch points. The frame is mounted above a standard Full HD television set. The frame, the TV set and a small computer are built into a table-like construction that is easy for users to interact with in a way that feels familiar in the real world (see Figure 8).

UX metrics and other gathered UX data

Additionally to the metrics we collect qualitative data, for this purpose we choose one of the most common data-collection methods, the questionnaire [15]. Based on the situation that the UX test occurred on a public place and not in a controlled laboratory setting, we reached only 27 players of the more than hundred that used the table. Another difference to a standard UX test was, that we didn't have any task definitions. The players came and played without any restrictions. Therefore we couldn't hand out a questionnaire for every player. Some of them played only 10 seconds and others watched their families and friends before they themselves touched the screen. To get more reliable data, we used the methods of user observation, video recordings and touch point tracking. Next, we discuss the UX metrics, which we defined for our test.

UX metrics of the touch point tracking

We use metrics, which test effectiveness and efficiency. We measure these metrics based on the following questions:

- How long does the test take?
- How long does the system run on autopilot?
- How often is a mini-game open?
- How many games are played from start to finish?

- How long is the mini-game and the panel view open? (measured in percentage and time)
- How long is a help-text open? (distinction between *at the beginning* or *during* a mini-game)
- How many touches are on the navigator?
- How many touch points occur? (at all and in every mini-game)
- How often do the players that play a mini-game stop this game before it is finished?

UX metrics of the video recording

We use metrics, which test effectiveness efficiency and learnability. We measure these metrics based on the following questions:

- How many visitors are standing a few steps away from the table and play?
- How many players use wrong gestures?
- How many players use wrong gestures, read the help text and after that use right gestures? (i.e. is the help-text useful?)
- Does the system accord to the expectations of the players?
- How long does it take that a player touches the screen after the system started the autopilot?

UX metrics of the questionnaire

We use metrics, which test effectiveness and efficiency. Additionally, we use qualitative questions to measure satisfaction. We want to know something about the age of our players, the recognized Pitoti and the satisfaction of the players with the game and the handling of our multi-touch table. We measure the metrics and the satisfaction with a questionnaire based on the following questions:

- How old are you?
- Did you recognize the figures on the rock panel?
- Did you feel rather entertained than informed?
- Do you think that you have learned something about the Pitoti?
- Did you recognize the game entry points on the rock panel?
- Did you play games?
- Did you recognize the navigator?
- If yes, do you think the navigator is useful?
- What do you think about the interaction of the multi-touch table?
- Was there a situation where you felt unsure or uncertain?
- Do you have a smart phone or tablet?

RESULTS

The four different UX data collection methods we use in our second test yield satisfactory results. We observe, that our game has only a few interaction weaknesses. We use the gained knowledge to improve our multi-touch table and make it more enjoyable and exploratory. In the following we report our results and their effects in detail.

Results of the touch point tracking

Collected data	Time[1]/Number
Testing time	07:46:01
Autopilot time	00:15:03
Played mini-games (from start to finish)	122
Aborted mini-games	23 (= 15,86% of all mini-games were aborted)
Total played mini-games	145 (= 03:55:31 or 52,55% of the total testing time)
Panel view	03:35:27 (= 47,78% of the total testing time)
Help-text open (panel)	00:04:59
Help-text open (before[2] a mini-game starts)	00:15:20
Help-text open (during a mini-game)	00:01:21
Help-text open (before and during the game: warrior)	00:03:42
Help-text open (before and during the game: hunter)	00:04:42
Help-text open (before and during the game: deer)	00:04:18
Help-text open (before and during the game: catch the horses)	00:03:57
Touch points navigator	181
Touch points panel	13.829
Touch points mini-games	27.456
Touch points mini-game: warrior	11.152 (by an average of 318,63 per game session)
Touch points mini-game: hunter	5.447 (by an average of 136,18 per game session)
Touch points mini-game:	4.082 (by an average of

[1] Time: the time designation is hh:mm:ss

[2] The system opens the help text each time a player starts a mini-game.

deer	131,68 per game session)
Touch points mini-game: catch the horses	6.775 (by an average of 173,72 per game session)
Touch points total	41.285
Selection mini-game: warrior	35 (= 01:13:29 of the total testing time)
Aborted mini-game: warrior	4
Selection mini-game: hunter	40 (= 00:48:38 of the total testing time)
Aborted mini-game: hunter	6
Selection mini-game: deer	31 (= 00:40:52 of the total testing time)
Aborted mini-game: deer	6
Selection mini-game: catch the horses	39 (= 01:12:32 of the total testing time)
Aborted mini-game: catch the horses	7

Table 1. Results of the touch points tracking

Analyzing the results, we observe that the mini-games and the panel view are used an approximately equal time slice of the total time (47,78% panel, 52,22% mini-games). It is a good result because we assume that the panel as well as the mini-games are equally attractive for the players. Furthermore, the four mini-games were played with equal frequency.

Only 23 out of 145 games were aborted during a session. Considering the many players around the table and the many different intentions, we are satisfied with 15,86% aborted mini-games. During the games, the players did not open the help-text very often. Figure 10 shows a density map of the touch point from a mini-game. In combination with the video analyses we assume, that the interaction design is efficient and simple enough for an ad-hoc play with intuitive gestures in public places.

Figure 11 shows a density map of the panel view. There are only 181 out of 13.829 touch points on the navigator. We assume, that the players recognized the navigator not as an interaction element but as an information element. The system runs only two times on autopilot. Therefore, we expect that an at-rest state of 5 minutes is suitable.

As mentioned above we want to measure metrics, which test effectiveness and efficiency. Based on this data, we got the necessary information for further development.

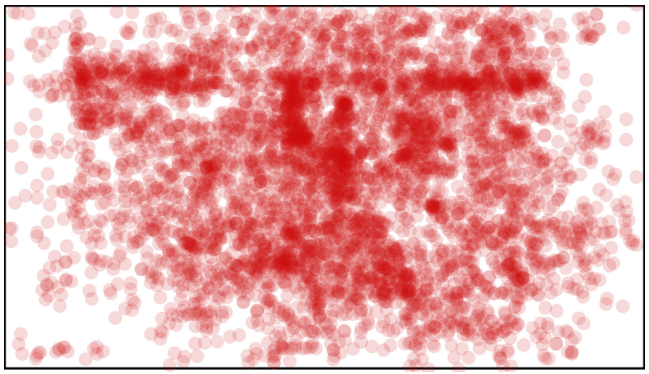

Figure 10. Density map of the mini-game "Put the clothes of the hunter on".

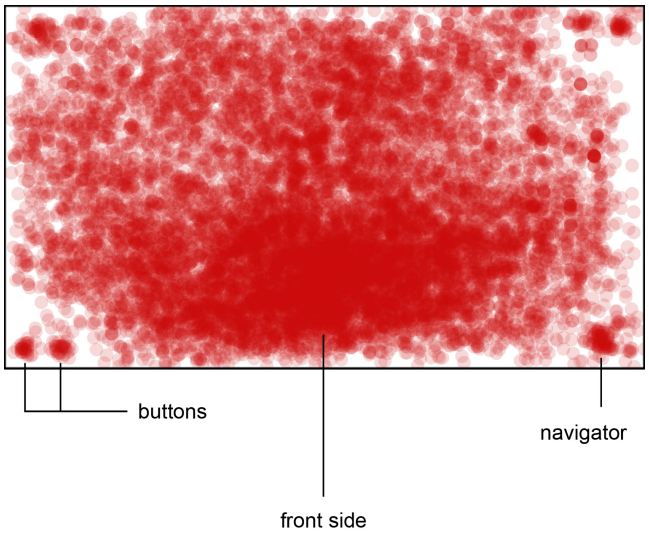

Figure 11. Density map of the panel view with 13.829 touch points.

Results of the video recordings

The analysis of the video recordings results in quantitative outcomes.

How many visitors are standing a few steps away from the table and play?
If there were adults around the multi-touch table, only three of them were playing at the same time. If there were children as well around the table, the adults tried to help them and played with them. The number of active players increased up to five players in combination with children.

How many players use wrong gestures?
The exact number of players, who used wrong gestures, couldn't be identified because of the large number of players. But we observed some players, who used wrong gestures at the beginning of their interaction.

How many players use wrong gestures, read the help text and after that use right gestures? (ergo help-text is useful)
As mentioned above, the exactly number of players, who used wrong gestures, couldn't be identified. But the players,

who were observed using wrong gestures, read the help-text. After that, they used the right gestures.

Does the system accord to the expectations of the players?
The system accorded to the expectations of the players mostly. Only a few players tried to tap on the navigator. Other players tried to zoom with their thumb and finger. But they performed the gesture to fast (like fast pick) for the system, so that the system didn't process the data.

How long does it take before a player touches the screen during the system runs on autopilot?
After 3 seconds, the first player touched the screen.

The evaluation of the video recordings shows, that our table has an attractive effect on visitors. Even two young kids (age: about 10yrs) played together without any help by their parents or other players. Many people worked around the table and collaborated when playing the game. We assume, that only a maximum of three adult players work together because they don't want to disturb or interrupt the others. Furthermore, we assume that our used gestures are intuitive and easy to learn. The help-text is useful because players who used wrong gestures, used the right ones after reading the help-text. Only a few players tried to tap on the navigator. However, considering the number of total touch points on the panel (13.829) and on the navigator (181), we assume that players realize our navigator as such. Moreover, we notice a high level of communication between players who don't know the other players on the table.

Results of the questionnaires

The results of the questionnaires are quantitative and qualitative. The data is divided into nominal data, ratio data and open-ended questions. We want to know something about demographics (age) of the players, the information content they get from the application, the frequency of using a touch device and the feelings when they interact with the table. To get meaningful and representative data, we handed out 27 post-test questionnaires to those who interacted with the table more than two minutes.

Most of the players who filled out a questionnaire are at the age of 21-30 years and 41-51 years. That doesn´t necessarily mean that we missed our defined target group (10-18 years old students). But based on the situation that the UX test occurred on a public place with a wide range of various ages, and not only our target group, we handed out the test to older people as well. Furthermore, we want to know if the players recognized the Pitoti on the rock. We observe, that every player has seen the Pitoti. The next question offered multiple choice. 24 players think that the table is more entertaining, 11 players think that the table is more informative. 15 of 27 players think that they have learned something about the Pitoti. 26 of 27 players found the Rosa Camuna as entry point to the mini-games. 25 of 27 players played a mini-game. Only two players just explored the rock panel and the prehistoric Pitoti on it. Five players comment beside their answer: "It was very funny", "If I had more time, I would have played even longer", "It was easy to use", "Very easy", "Yes, my children played and I watched them", "Yes I played because a game was opened when I came to the table". 17 of 27 players noticed the navigator. 10 players did not notice the navigator. 14 of 17 players who realize the navigator indicated that it is very useful. Only one player indicates "no, the navigator was not useful". The next two questions were open-ended questions so that we got many different answers. We asked: *"What do you think about the interaction of the multi-touch table?"* The answers are: "Easy", "Cool", "Coherent", "Super", "Very intuitive", "Easy to understand", "Very good gesture identification". *"Was there a situation where you feel unsure or uncertain?"* 13 of 27 of the players filled out "No". The other players wrote: "Yes, only when the puzzle element didn't fit into the outlines of the warrior", "Only at the beginning of playing", "By trial and error I recognized the right gestures". 15 of 27 players have a smart phone, 6 of 27 have a tablet and 11 of 27 have neither a smart phone nor a tablet.

The post-questionnaires show, that not only our target group but also younger and older people are able to interact with our game. 13 of 27 players were over 41 years. We assume, that the interaction design and the game design are simple to understand & operate and entertaining both for the young and the older people. Although many players indicate that they don't have a smart phone or tablet, they interact very easy with the system. Players of the older generation explore the rock panel deeper than the kids. We expect that most of the kids are more interested in playing games than exploring the rock panel. Every player recognized the Pitoti on the rock panel. 24 players think that the table is more entertaining, 11 players think that the table is more informative. Hence, a third of the players didn't learn anything about the Pitoti. 10 players did not notice the navigator. We assume, that the players only played a mini-game or spent less time on the panel view. Analyzing the open-ended questions, we get positive feedback in relation to our game design and interaction design. The players feel familiar with the gestures or learned them very fast. And they wrote that the system tracks the gestures very fast and enables a smooth movement.

The questionnaires were a good method to receive some personal impressions and feelings in addition to the metrics.

Results of the user observation

During the UX test, an observer took notes of all remarkable occurrences. We observed the players, recording both performance and comments. We find out that the players have a problem with the indication of the scale on the navigator. They don't understand the number that is displayed under the navigator. Furthermore, we noticed that people (even children and adults) who don't know each other played together without any inhibitions.

Many players tried to zoom and pan with four or five fingers. But after trial and error they noticed that they can only use two fingers for zoom and one finger for pan. The white circle around a fingers' tap works as a helpful interaction feedback from the system. The players know immediately whether their gestures work or not. And a child asked her mother: "Mum, could you buy such a table for me?"

CONCLUSIONS AND FUTURE WORK

In this paper, we presented a game concept and the UX test of the implementation of an educational archaeology game. We implemented five different games and buttons with interesting and useful background information embedded in a full-scale image of a rock panel. The performed second UX test with largely good results enables us to improve our application. We found out that it is important to use more than one test method to collect as much as possible data about the UX. Furthermore, we can say that the defined metrics can be used for measuring the UX of multi-user applications on multi-touch tables in general. In our current game design and implementation, we identified four problems and possible solutions.

The players do not get enough information about the Pitoti.
We could implement an icon beside interesting Pitoti on the rock to access additional information on this Pitoti. The icon with an "I" (stands for "information") in it is designed like the Rosa Camuna on the panel that serves as entry point to a mini-game. Furthermore, the *Anonymous Button* can include more detailed information about the Pitoti and Valcamonica.

Most of the kids are more interested in playing games than exploring the rock panel.
The final UX test will be in a museum with archeological and anthropological background. The exhibition will contain more exhibits about the Valcamonica. In this context we assume, that a user of our table will be more interested in exploring the rock panel.

The questionnaire provides to little information about the knowledge that the players obtained about the Pitoti during the game.
To verify whether the player gets information about the Pitoti, we should rework the questionnaire. With questions about the figures in the games or the valley Valcamonica we could figure out how informative the application is.

The scale on the navigator is confusing for the players.
We could change the scale labeling of the navigator. In addition to the new scale labeling we could include a description, which is opened by a tap on the navigator.

Future work will include a) the implementation of the design improvements the results of the UX test suggest; and b) another UX test gathering information about what the players have learned.

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