Lost Lab of Professor Millennium: Creating a Pervasive Adventure with Augmented Reality-Based Guidance

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ABSTRACT

This paper presents a pervasive adventure production called Lost Lab of Professor Millennium that experimented with different kinds of interaction techniques evaluating how they affected the adventure experience. The paper further reflects on the practical organization of the production targeted for schools and students between 12 and 15 years of age. Groups of up to four teenagers navigated through thirteen different kinds of pervasive computing experiences in checkpoints sharing a device providing augmented reality (AR) (MapLens) on a physical map and an adaptive marker-based AR guidance. Based on a Professor who lost her technologies, the story of the adventure provided a unifying narrative also through her fish Linus guiding groups through a variety of tasks in the checkpoints. The production was evaluated with direct observations, different kinds of video recordings, interviews and questionnaires. The evaluation revealed how groups shared the devices and performed collaborative interactions with the devices. The production received positive feedback from all stakeholders, but in terms of feasibility had some drawbacks. The evaluation indicated that the marker-based AR guidance techniques is practical, reliable and easy-to-use, and can be also used as a storytelling or story enhancing technique.

INTRODUCTION

Computer and digital technology has been used in pervasive experience for decades. Ranging from museum audio guides to more established productions such as Pac-Manhattan and Uncle Roy All around You, there is a wide range of previous work in the creation of computer-supported experiences that aid and augment exploration of physical spaces and sites. Computer systems can be used in different ways to support pervasive experiences such as route guidance and navigation, communication and storytelling, and interaction with physical space. In the Lost Lab of Professor Millennium, like in many other pervasive games and experiences, we use all these aforementioned approaches.

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ACE '14, November 11 - 14 2014, Funchal, Portugal Copyright 2014 ACM 978-1-4503-2945-3/14/11 $15.00
http://dx.doi.org/10.1145/2663806.2663844

Mobile devices are often used as primary interaction device in pervasive experiences. Over the years mobile devices have been developed in terms of computing capacity, networking, sensing, camera capabilities and interface. From the production perspective the experiences can be divided into three categories: pervasive experiences that utilize specially built mobile devices, experiences that utilize commercial off-the-shelf devices, and experiences that use the participants' own devices. In the Lost Lab of Professor Millennium, we decided to utilize standard off-the-shelf mobile phones, but use only one reference device in order to minimize development costs.

Why are pervasive computing supported experiences important to study? Pervasive computing techniques have the potential to influence how events, our physical shopping experience, outdoor and public signage and advertisements are organized, and how cultural and leisure sites are produced. These techniques allow new affordances for leisure activities in outdoor or public spaces, and enable new kinds of public performances and productions. Overall, pervasive computing techniques have the capacity to impact the social, experiential and commercial aspects of public space. For more on the benefits, backgrounds and challenges related to pervasive computing techniques in entertainment see [15, 8].

The Lost Lab of Professor Millennium was specifically focused on exploring how to develop a pervasive computing supported event production that utilizes augmented reality (AR) in navigation and guidance, and allows the participants to interact with the surroundings directly or through mobile devices. The target group for the production was middle school children. The production was aimed to inspire students to understand how several layers of technology surround us.

Pervasive Games and Services

There are several sites that are hosting pervasive computing experiences. The most common technical support in site exploration are audio guides, which are used in many cultural sites and museums. Many sites are exploring the use of mobile phones and interactive surfaces for guiding visitors and making the experience more immersive [20]. Mobile phones are used for either stand-alone tourist guide applications, and in applications that are triggered with some surrounding sensors [3]. Some museums and cultural sites have also explored the use of AR [14].

City orienteering is another place computing is used to enhance site exploration and site-specific experiences. There are different ways that city orienteering can be organized, but the most common way is using a GPS-based map interface and some kind of check-in systems such as NFCs or QR-codes in the sites. Orienteering is utilizing a digital check-in system called Emit.

In addition there are different kinds of global location-based recommender systems such as Foursquare, Google Maps and Here. Also sports hobbyists are using different kinds of pervasive technologies for aiding navigation or logging the experience. Pervasive games utilize a variety of technology and range from storytelling driven role-games, to different kinds of adventures, to pervasive battles in virtual games worlds which are linked to the physical world [5, 2, 1]. Overall, navigation aid, communication and storytelling, site exploration, logging experience and recommendations, and game orchestration can be considered as main features of different kinds of computer supported pervasive experiences.

Augmented Reality Navigation

There are at least five different scenarios for how AR can be used as an aid in navigation in a game (cfr. [19]). One common way is to use device compass and location data to display guides through a camera view. Alternatively, AR can be used in navigation by displaying location information and other navigation cues on top of a physical map. This technique is called MapLens [16]. Alternatively, there is a way of displaying navigation cues on top of a camera view, based on site tracking using point clouds and location information. All of these techniques are mainly based on location information provided by global positioning systems. Indoors this is not available and in order to provide indoor navigation, some kind of network mapping or location sensors should be set up. The fifth scenario is to set up navigation signs in physical places. The navigation markers are aware of their location, and then the visual sign on top of the navigation marker is defined based on the users' path preferences and the server-based route definition system. We call this technique as Space Layer.

Local Interaction

A variety of approaches and techniques have been explored to support local interaction, which usually involves some kind of installation, including bodily and mid air gestures [6], voice input [10], virtual characters, mobile phones and public displays [12], large multitouch screens [4] and a variety of other strategies [7]. Local interaction in the Lost Lab production means basically that the mobile device can be used to interact with the site-specific computing system with sensors, actuators or shared interfaces. This space can have, for example, different kinds of large screens, light systems, audio systems or sensor-based installations that can be interacted with through the device. Interaction through the device is usually performed by utilizing the internet connection capabilities of the device and by connecting the space equipment to the same internet server. The problem of using the internet connection is that the latency of the connection is often relatively long for seamless interaction. Alternatively, interaction through the device can also be performed by utilizing some local communication system such as Bluetooth. In the Lost Lab production the local interaction was performed by using a local access point with proxy, so that the communication between the device and space components was achieved through local access point and not through the cloud.

EXPERIENCE DESIGN

The Lost Lab production was developed as a collaboration between a large local event and a research project. The event was hosted in a temporary pavilion with a 500-person capacity. The event theme was technology, and hence the production theme evolved around the same topic. The research project's goal was to develop a platform that combines AR, large public screen interfaces and local interaction. The platform was developed as a combination of techniques developed in the research groups affiliated with the project. Developing the first iteration of the platform based on needs of an in-the-wild production was expected to inform design of further evolutions in a practice-led fashion and focusing the in-the-wild constraints as explained by Benford et al [2]. The technical research team was complemented with a group of production designers for concept and story development, and for production design of different site-specific experiences.

Production Elements

Due to the funding and stakeholder composition there were several predefined production elements that created the baseline for the production. The primary objective for the production was to combine different pervasive technologies developed by associated research groups: different AR tracking techniques (point-cloud, image markers, fiducial markers), a large playful multitouch screen interface [9], and local space interaction system [18] so that the we could explore these prototype technologies in in-the-wild conditions. This created the baseline for the production setup. Other predefined elements were event location, event theme, target group, and event duration (3 weeks). There were four venues in the neighborhood of the pavilion that created partnership with the production (i.e., music house, museum, library and office house with publicly available lobby).

The target group was school classes with students between the ages of 12 and 15 and in groups of three. Each group would have a dedicated device, which would be in this case a Nokia 1520 - a large 8-inch mobile phone with 8 megapixel camera and 4G connectivity. The core activity in the experience would be visiting different sites, which we called checkpoints, and performing different tasks in each checkpoint. Due to external constraints, the experience was approximately 1.5 hours long. In order to minimize queuing and create a smooth experience, it was decided that groups should have a unique route, which also meant that the platform should be able to guide all groups specifically to their checkpoints. For this reason there should be at least as many checkpoints as there are groups.

In order to realize the guidance and navigation through checkpoints we decided to use two different techniques: physical

Figure 1. Professor Millennium talking to the students via the screen.

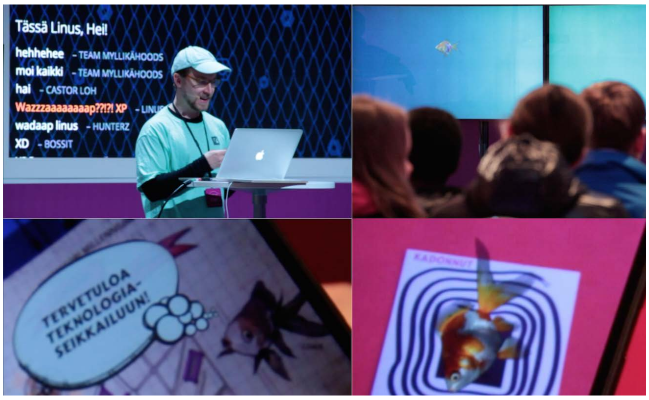

Figure 2. Four instances of the fish story agent Linus: on a chat screen as text (top-left), swimming on a touch screen as an animation (top-right), on a map augmented with a text bubble (bottom-left) and as an augmented guidance sign (bottom-right).

map augmentation (MapLens)[16] for outdoor navigation and marker-based AR route guidance, especially indoors. The design of the core structure was decided early, but the checkpoint design and route design was expected to change still during the production, which meant that there was an interface in the platform that allowed modular introduction of new checkpoints and management of route. This decision limited the possibility of having checkpoint-specific interfaces in the native client, but all interfaces should be based on the web interface embedded in the native client.

Story and Storytelling

The story and storytelling was divided into two parts: an overarching story that would initiate the story and inform the design of production visuals and naming, and the design of each checkpoint. The biggest challenge for the story concept was to match site-specific exploration and the technology theme originating from the event. The challenge was emphasized by the fact that none of the locations had a special emphasis on technology. The story was based on a fictional professor, called Professor Millennium, who in an explosion had lost her technologies around different places and asked student groups to go around the area in order to look for these technologies and collect them for her. Fig. 1 shows Professor Millennium appearing in the big screen inside the Pavilion, introducing the backstory during initiation while students are watching.

It was important to develop a storytelling agent that would provide continuity. We decided that the storytelling agent could also introduce some of the tasks in the checkpoints and enable the support interface for students through mobile interface. Instead of making the professor the storytelling agent, it was decided that a more playful, engaging and more easily animated character should be the storytelling agent. For this reason, the Professor's pet fish Linus was developed. In the final design Linus would appear on the public screen interface, in the mobile device through a chat interface, in the map and in the guidance markers. Fig. 2 shows the storytelling agent Linus in different mediums.

In order to increase the visual side of the story and make the story more memorable, students were asked to take pictures in different checkpoints that realize the technology collection aspect of the story. The pictures taken from the mobile devices would be processed by the platform and visualized in the memory wall in the pavilion, which would function as a core activity during the final celebration. The team wanted to focus the experience around exploration and collaboration, and for this reason it was not a game or competitive. There was no point scoring, and the experience was advertised as a technology adventure, in order to prime students and teachers that they were not coming to a game. We included elements of playfulness [13] in the experience with the help of the Playful Experiences (PLEX) Cards [11]. The collection of technologies through checkpoints would qualify as awards, such as in some games, and for this reason this experience would also qualify as a pervasive game.

Checkpoint designs were iterated while the production was still running. The number of checkpoints was balanced between how many groups we had and how many checkpoints we could realize with limited resources (e.g., how many devices we could provide, how many checkpoints we could facilitate with different tasks and how many unique and suitable sites could be found from the different venues) and limited time (1.5 hours). Ultimately the number of checkpoints was set to 13. The checkpoints could to be categorized as installations, live interaction with Linus, physical activity, and AR exploration based on the point cloud technique. Some of the checkpoints were combinations of two different categories. Table 1 provides an overview of the checkpoints designs and tasks. Technically each checkpoint had a significantly different structure, which was also one of the research objectives.

Production Operations

The production development was performed mainly by the research project theme complemented with the performance design professor and her students. For the production there was a group of support staff for helping to prepare the sites and support students during the checkpoints and the initial celebration in the pavilion. The production group consisted of 15 members including technical team, production designers, concept developers and communications persons and 16 production helpers. Most of the design meetings during the preproduction period were organized on-site in order to make the production team familiar with the sites and have close access to check site-specific details.

Table 1. Checkpoint designs and tasks.

No.	Type
1	Live communication (explore history of the site)
2	Big screen navigation (explore information structure)
3	Physical communication exercise
4	Live communication (discussion about technology)
5	Depth-of-field camera (exploring sound creation)
6	Point-cloud exploration of a statue (statue history)
7	Point-cloud exploration of a statue (statue history)
8	Site-based reflection (history of postal system)
9	Local interaction with lights (exploring light control)
10	Live communication (future of library system)
11	Site-based reflection (technology related to clothes)
12	Big screen interaction (news publishing tech)
13	Transparent display (exploring display technology)

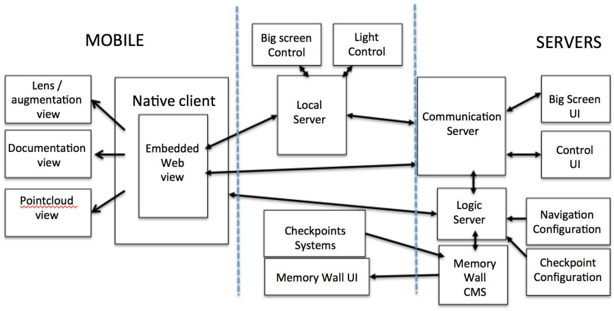

Figure 3. System architecture divided into mobile (native client and embedded web view), checkpoint (local server, memory wall UI and checkpoint documentation system) and server systems (logic server with configuration files, communication server including extensions and memory wall CMS).

The production had 13 runs. Each run had 8-12 groups and 20-45 students simultaneously. Each session lasted for 1.5 to 2 hours, and during this time only a few groups in each start managed to complete all 13 checkpoints. Hence, in all starts the groups were finally called back before all groups managed to accomplish all checkpoints. There was a special callback function in the platform, which activated a callback in the checkpoint interface, the AR map and in guidance markers.

Most checkpoints had a crewmember assisting or monitoring. In all checkpoints the crewmember was not necessarily actively involved in instructing or guiding for the tasks, but the students could accomplish the checkpoint task by following instructions received from the mobile device. There was a special crew chat for coordinating production operations, which were led by the game master. Overall, the game master had three instruments for managing and monitoring groups: crew reporting in crew channels, groups talking in checkpoints and in general chat, and then a platform monitor system that showed the progress of each group.

Preparation for each day took roughly 1.5 hours, which consisted of preparing the checkpoints, checking all guidance markers, and preparing the devices. The introduction procedure started with Professor Millennium appearing, explaining the backstory, introducing Linus and giving the floor to the Professor's assistant who would then introduce the device and application, how the map works, how to interact with Linus, how navigation happens with markers (by showing the first marker on the big screen), the first arrival routine to a checkpoint (checkpoints were activated with special markers), how to take a picture (the zero checkpoint was about taking a group selfie), and finally showing how to get help through the general Linus chat. In the final part groups were also invited on stage to browse the memory wall. Organizing a synchronous final celebration was complicated since some groups arrived much later to the pavilion even though the callback was initiated simultaneously.

PLATFORM

In this chapter we will introduce the different aspects of the Lost Lab platform. First we introduce the overall technical architecture, then focus in more detail on the navigation and guidance system, explain the live communication, local interaction system, the technical designs of core checkpoints, and finally introduce the memory wall system. During the production the platform functioned as a complete integrated system, but in practice most components were designed and developed separately and have standalone utility. Only the logic server and mobile client did not have stand-alone utility and were designed for this production specifically. Other systems were modified to support the production and integrate with each other.

Technical Overview

The basic architecture of the system was composed from five core software components: mobile client, logic server, interaction server (with mobile, screen and control interface), local interaction extension, and memory wall system. Fig. 3 illustrates the design.

The mobile device had two core parts: lens and journey. The lens was used in the AR MapLens interaction and guidance markers. The journey was used to access the communication server interface, including checkpoint interface, and realize the interface for local interaction. There are three different servers in the system, which makes the overall architecture appear complicated. The main reason for having separate logic and communication servers is the software component history. The local server has a unique quality and for this reason needs to be a separate component.

Augmented Map

There were two guidance systems in the story that helped students find checkpoints. The first one was a physical map, where the group location and next checkpoint appeared based on see-through mobile device augmentation, which is similar to the MapLens design [16]. In addition to navigation cues the map also visualized awards from completed checkpoints and text bubbles of Linus hinting about the next location. Fig. 4 shows the map design and the augmented map.

The map designed had many details to enable easy tracking for the augmentation system. During the design phase we explored different visualizations and animation. For example, different kinds of 3D models of sites were eliminated from

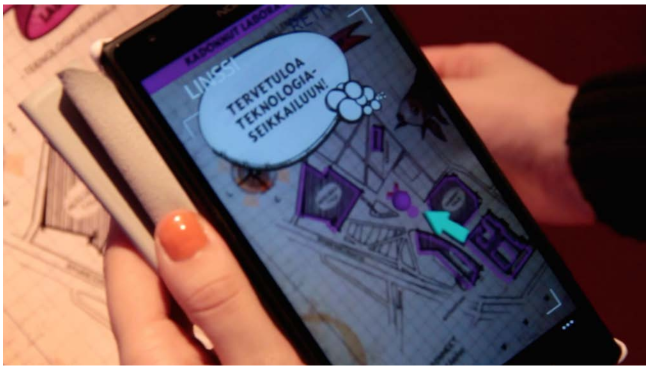

Figure 4. Person holding physical map, and mobile phone showing location, direction, hints and rewards augmentations on top of physical map - MapLens interaction.

Figure 5. Markers on the large screen (top-left), students using markers (top-right), and markers with fish augmentation (bottom).

map augmentation because they appeared to reduce the readability of the map. In the final iteration, the map augmentation had only one animated feature, which was an arrow that pointed at the entry point to the building where the next checkpoint was located. The route that the groups walked was illustrated in the map as a trace. This design was chosen in order to help groups orient themselves. Checkpoint locations and arrow directions could be configured in the logic server.

Marker-Based Guidance

The augmented map could not be used efficiently indoors for three reasons: GPS signal is not usually available indoors, the map is not detailed enough to enable indoor navigation and there are several floors inside the buildings, which is a challenge for map visualization. For this reason, we decided to develop a complementary guidance system based on augmentation on top of fiducial markers. In the production we had approximately 50 markers located both indoors and outdoors. The markers had either a Linus fish swimming in a specific direction, similar to an arrow sign, or then some specific text or another image guiding near stairs and doors, or in general places where a simple arrow was not instructive enough. Fig. 5 shows a marker sign and a marker with augmentation. The markers were mounted both on walls and floors, and the size of the marker varied.

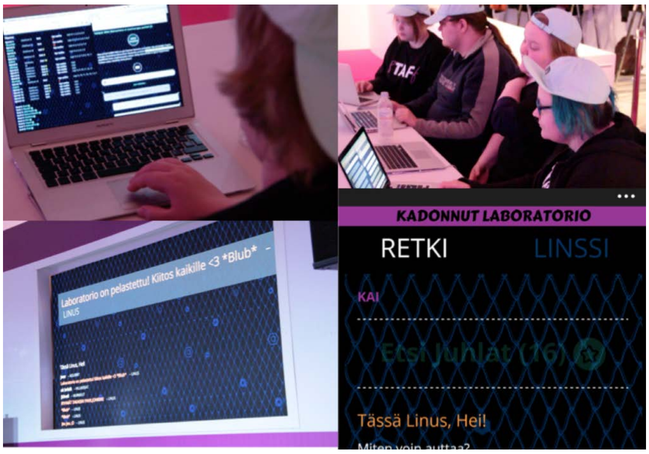

Figure 6. The communication system: control interface (top-left), chat moderators (top-right), large screen interface (bottom-left) and mobile web interface embedded in the native client (bottom-right).

Each sign was unique and their location and orientation predefined. Each guide marker was configured so that they could lead to any of the checkpoints or the pavilion depending on where the groups were going. We called this navigation technique Space layer. In this case the most important part for using dynamic qualities of marker guidance was in the beginning of the experience when all groups had a unique starting point, when groups got lost, and in the end, when a callback was devised and all groups were instructed to return back to the Pavilion simultaneously. Hence, the guidance markers were both group destination adaptive as well as temporarily adaptive.

Communication Server

Communication with groups was performed by utilizing a live participation system. This system was modified to accommodate unique group-specific views for each checkpoint, which were launched from the mobile client, and matched the visuals of the experience. In addition, the system was modified to allow chat moderators, who acted as Linus in the general help thread as well as in specific checkpoints, control functions such as defining when groups can pass a checkpoint, moderating certain messages, and automated pass functions in checkpoints. Finally the control interface was enhanced with a group monitoring function that showed which checkpoint groups were heading to or which checkpoint they were at currently. The interfaces of the communication system are shown in Fig. 6.

Local Interaction with the Device

Local interaction was enabled by utilizing the Spaceify platform [18] that allows local interaction between a mobile device and space elements through a web interface by utilizing a proxy server in a local access point. The local server is useful, because it allows easy configuration (if you are on-site and in the local area network, then you can interact) and interaction is robust and has low latency. In the Lost Lab production the local interaction through the Spaceify platform was used in two checkpoints: light interaction and big screen interaction through a magazine newspaper website. Both of these checkpoints demonstrated different kinds of site-specific interaction scenarios through a mobile device. In both cases the platform was operational and integrated to the client system, but the Windows mobile platform handover from 4G network to local network was ultimately unreliable in the actual productions, due to multiple connections open between global servers and the client, and ultimately the experience was delivered so that in each checkpoint there was a host who had a spare phone that allowed groups to realize the interaction.

Checkpoint Technologies

Besides chat interaction and local interaction checkpoints there were also other computer-supported checkpoints in the production. Two of the checkpoints were based on markerless AR point-cloud exploration, one checkpoint was based on transparent display, one was based on depth-of-field camera triggered music interaction, and one was a large public multitouch wall navigation exercise.

The point cloud exploration was based on an AR technique where instead of a visual picture marker there is a 3D point cloud as a marker, and the augmentation can be placed on top of this 3D point cloud. This technique was expected to be suitable in site exploration and for displaying some context-relevant information on top of buildings and other site-specific objects. In practice, the point cloud technique was not entirely reliable in all different lighting conditions and due to integration challenges the point cloud exploration checkpoints were implemented in the final version by using a spare device similarly as the local interaction.

In the transparent display, the exercise goal was to draw group members' faces through a display. The idea of this exercise was to trigger new perspectives on what kind of affordances new display technology could enable. Each group member had a limited time to draw their friend's face who was sitting on the opposite side of the display. In the large public multitouch checkpoint students were asked to navigate through a graph interface and find specific information. The system used in this checkpoint was the same as that used in the memory wall system introduced in the next chapter.

The memory wall was created by utilizing the Kupla platform [9]. Kupla is a large multitouch interface system with spherical physics modeled widgets. Kupla has been developed as a lobby screen, for events and for different kinds of workshops. In the memory wall function all pictures taken by the groups in different checkpoints were sent to the memory wall and groups could browse their pictures in different ways. The memory wall interface is shown in Fig. 7. The memory wall was used as an instruction device during the initiation where and allowed kids to play with Linus the fish.

EVALUATION

Participants

In total 49 participants (31 male, 18 female) took part in the detailed evaluation. This accounted for one or two groups per each run. Although we are aware that gender may affect group interactions, the recruiting process was constrained by parental consent, and as a consequence gender distribution could not be controlled. All the participants were students from middle schools in the Helsinki region and were all aged between 11 and 15. Participants in the evaluation were in groups of 3 or 4 people and we evaluated a total of 18 groups. Half of the groups were composed of only boys, 5 of the groups were made up of only girls and 4 groups were mixed.

Figure 7. Students using the memory wall to browse their pictures.

Procedure

Only kids who provided signed parental consent were involved in the evaluation part. The production runs took place in the morning under different weather conditions (i.e., sunny, cloudy, rain, hail, light snow). Each group was followed by one experimenter, who video-recorded and observed the entire session. The kids were explicitly told that one experimenter was following them and recording their behaviors. The experimenter observed the kids without interfering with their activities, i.e. from a certain distance, and she was not able to sense subtle group dynamics. Therefore in some cases (2) one member of the group wore camera glasses (i.e., Pivothead) in order to record all the details of the group interactions. Once the game ended, the kids were asked to fill in a short questionnaire and to answer 3 open questions.

Method

The Social Presence Questionnaire (SPQ) and the In-Game Questionnaire (I-GEQ) were employed. Both scales are part of the FUGA questionnaire [17]. We chose not to administer the FUGA questionnaire in all its parts, in order to prevent boredom in kids and consequent random and inconsistent answers. The SPQ consists of 17 items and aims at assessing to what extent the experience could be able to involve participants not only with the experience story and flow, but also with the other peers participating in the experience. The I-GEQ (14 items) was included with the intent to gather participants' general feelings with respect to the experience. In both questionnaires participants' had to state their level of agreement or disagreement with each item on a 5-point Likert scale (with 1 indicating strongly disagree and 5 strongly agree). Items understandability and comprehensibility was tested beforehand with a 12-year-old child. Questionnaires were presented in Finnish. After they had finished completing the questionnaire, they were asked three open questions to get comments on (1) their general impression of the game; (2) the group interaction with the guidance avatar, i.e. Linus fish, and

(3) their management of the eventual issues emerged. Questions were asked either in Finnish or English, according to participants' preferences, and were recorded.

FINDINGS

Within-Group Interaction

We observed four main types of collaboration within the 18 groups: *leader, flexible group, fixed group, and flexible leader*. First, in half of the groups (9/18) there was a clear and driven *fixed leader* that not only held and interacted with the device, but who also defined the pace at which the group advanced between tasks. In these groups the roles were fixed, and thus there usually was a second player whose main role was to hold the map in their hands and put it up for consulting it upon the leader's request. Sometimes, the leader would also take the map with their other hand and use it to check their group's current location leaving very little for the other group members to do. G12, which consisted of four boys, was the only case where there were two leaders leading the whole experience. In such groups, the remaining one or two players were mainly following the leader(s) around.

Second, some groups (4/18) acted as a *flexible group*. In these groups there was no clear leader and there were no predefined roles. Players in these groups nicely collaborated, naturally swapped the map and the device, discussed together about where to move next, shared who would go and check the location of markers, and had an equal amount of motivation and responsibility when completing the tasks. Whenever it was their natural turn to hold the device, they would not seek the help from the other two group mates to figure out where to go next. Despite this marked individualistic use of the device, the group acted as a strongly bonded unit. Third, a few groups (3/18) behaved as a *fixed group*, meaning that despite having fixed roles (i.e., one used the device, another held the map, and the third followed closely), they managed to work as a cohesive entity. For example, in G3 the three boys were all equally involved in the game, participating in the hunt, looking for and pointing at markers when they found one. Finally, only a couple of groups (2/18) belong to the *flexible leader* type. In these cases, there was a clear leader who was making decisions, defining the movements inside the gaming area and speaking with the helpers at each checkpoint. However, in these two groups the device and the map were passed around between group members so they all had a chance to experience firsthand how to interact with the device.

All participants were generally motivated to participate in the experience. However, there were some exceptions whereby individual participants would either lose motivation along the way, check their personal mobile phones during waiting periods (G10), and even three participants who were never interested in the experience (G5, G9 and G17). For example, from the very beginning, a male participant from G5 isolated himself and seemed totally uninterested with the game, looking and following his group members from a distance.

Between-Group Interaction

During the game, half of the groups (9/18) came close enough to another group so as to potentially interact with one another. We observed three types of between group interaction: *merging, conversing, and competition*.

First, the most common reaction when groups met was *merging* (5/18), whereby both groups vividly talked or even worked together as a larger group of six, helping each other and showing each other what should be done. On one occasion, a group member from one group (G2) momentarily joined another group and was helping them out. Shortly after, she realized that her own group had moved on and quickly rejoined her group. Second, some groups were involved in *conversing* (3/18), meaning that one group member would briefly talk to members of another group, quickly sharing their experience of the game, often while walking from one place to another. Finally, we saw direct *competition* (1/18) between groups, especially in cases where the group leader was extremely motivated and would drag their group along. To our surprise, when two groups came together at a checkpoint, G2's group leader desperately tried to get ahead of the other group by running to the next checkpoint. Besides this case, there was no other observable instance of competition between groups, which is surprising given the game-like nature of the whole experience.

Besides having to share the space with other groups and the general public, students had to also deal with some sources of distraction. A few groups (3/18) were followed by their teachers while participating in the experience. Their interaction was mainly through verbal communication and scanning some markers. In addition, temporary exhibits at the Post Office and Library buildings distracted some participants (G8 and G9). Two groups (G14 and G15) were momentarily followed around by a journalist from a national newspaper, who wrote an article that appeared the following day in the press.

Guidance and Navigation

Overall, the groups were able to navigate to the different checkpoints. All groups used the markers for navigation and received some guidance from the volunteers at each checkpoint, but not all groups used the map guidance. Several groups either used the map very little, or even not at all (G12 and G16). While in theory, marker-based guidance was supposed to be more problematic as there is no fallback on GPS, it turns out that it was a very direct and fun way of navigation, which worked both indoors and outdoors.

Several groups (7/18) got lost at some point and used different strategies to overcome the problem. The first line of help came from checkpoint volunteers or from chatting with Linus using the device. A few participants went out and asked strangers on the street about where a certain building was located (G2). On two rare occasions, the observers intervened when students were wandering off limits (G14 and G15).

Checkpoints

Because of the nature of the experience, it was common to see the roles within the group mixing up, when the group reached one checkpoint. This was especially true in those checkpoints in which the crew helper provided the group with a second device: in those cases it was not the leader of the group - already holding the group's device - who would conduct the activity, but one of the other group mates. In some cases, after the first exchange of roles, the group became more flexible in terms of sharing the device and the map.

Moreover it was quite common that the student holding the device read aloud the messages on the phone to involve the other group mates in the activities. This was especially true at the checkpoints in which no helper was present and the groups needed to autonomously solve the task. In some cases, some of the students appeared to be reluctant in taking part in the activity proposed at the checkpoints (G10, G16 and G18). In general this was true for one member of the group while the others enjoyed the activity. However in G18 the leader of the group had to insist for a while to convince two other group mates to join her, while the fourth member of group simply stayed aside.

After the experience was concluded, the students could see all the pictures taken by all groups during the entire gaming session on the memory wall. Interestingly, in many cases the kids did not interact with the memory wall but simply sat down and waited for the debriefing. However when they navigated through the different pictures, the groups split up and the students explored the contents either independently or with other friends. We may say that the interaction with the memory wall dissolved the competitive dynamics belonging to the game and led the kids to enjoy the activity overall.

Quantitative Data

I-GEQ questionnaire [17] items can be clustered into the following dimensions: competence, sensory and imaginative immersion, flow, tension, challenge, negative affect and positive affect. Concerning competence the mean score was 2.44 ($SD = 1.09$), suggesting that the kids had the feeling of being skillful while playing the game. The dimension assessing immersion received a mean score of 2.22 ($SD = 0.92$), indicating that players were overall concentrated in the game. However when looking at the mean score for the flow ($M = 1,67; SD = 1.08$) and challenge ($M = 1.25; SD = 0.89$) dimensions, it seems that kids were not completely engaged with the game. Negative feelings, conveyed by the tension and negative affect dimensions, appeared to be nearly absent receiving poor scores (respectively $M = 0.75; SD = 0.93$; and $M = 1.07; SD = 0.79$). On the other hand players seemed to enjoy the game, rating favorably the dimension positive affect ($M = 2.55; SD = 0.96$).

Similarly, the items in the SPQ questionnaire can be clustered in 3 dimensions: empathy, negative feelings, and behavioral involvement. Respondents rated positively the empathy dimension ($M = 2.49; SD = 1.2$), suggesting that they felt connected to the other group mates during the game. Again, the dimension assessing negative feelings was scored poorly ($M = 1.05; SD = 1.1$). Kids seemed to actively contribute to the game, scoring the behavioral engagement dimension favorably ($M = 2.20; SD = 1.0$).

Informal Feedback

There was some informal data collection from the students through the chat channel and from the teachers through informal discussion after the production and through explicit feedback requests. Overall, teachers appreciated the experience significantly. Some teachers said the experience qualified as their best field trip in years. Many teachers asked whether they could have the same session again in following years. Most criticism was related to the story, which some thought could have been more refined. Also some checkpoints were considered too hard or not well-refined, and the purpose of the task was not entirely clear. Also many students were disappointed that this was not a game. Some students finally said that: "What's the point if you can't win?". The chat discussion was popular among some of the students. Students were also interested in understanding who was behind the chat avatars.

DISCUSSION

The production of a pervasive adventure is challenging and complex. The pre-production and design of this kind of experience is a combination of a game and movie production, but the operations compare to theater and event productions.

Interaction in Groups

Based on the data collected during the evaluation, we can conclude that the group arrangement around one single device is not optimal. In some cases this group arrangement led one of the group mates to be excluded from the game, as findings from both the observations (e.g. kids playing with their own mobile phones) and questionnaire (low scores in the flow and challenge dimensions) suggest. However, in many cases all the group mates were equally involved and enjoyed the game, suggesting that the way the device is managed by the group is highly dependent on the subtle internal dynamics of the group, rather than the quantity of devices per group. Interaction with the guidance agent (in this case the professor's pet Linus) was technically stable and a production-wise manageable component of the game. Groups used Linus often for help, but also interacted in very vivid ways with each other through the global Linus chat.

Interaction with the environment was technically more challenging; both local interaction and point cloud failed to work robustly, and for this reason the use was aided in specific checkpoints. However, the production group concluded that there are no major technical obstacles to make them ultimately work in a robust way. Overall, students liked the local interaction, and it can be considered as a relevant part of the overall design of the production.

Guidance and Navigation

Based on this experience the map augmentation navigation was not considered a particularly useful feature. The groups seemed to use the map quite infrequently even in outdoors, even tough it was a more widely available navigation aid than the marker signs (there were only 14 marker signs outdoors altogether). The design of the map was a somewhat complicated process and the final outcome was full of compromises between readability and visual appeal. Also, the map tracking had frequent offsets, which compromised the readability of the map. In summary, it probably would have been resource-wise, technically and potentially also story concept-wise equal or even a better option to implement the map feature by utilizing a digital map in the device.

The visual marker-based guidance was found to be robust, provided clear functional value over GPS-based map navigation, especially in indoors, was relatively easy to implement and configure, and extended the story feeling with the Linus visualization. Alternatively, we could have implemented a sensor-based indoor navigation system, but that would have been technically demanding, considering the relatively large area and four sites where the experience took place. Then again, by changing the story structure somewhat, traditional signage could also have provided a possibility for indoor guidance, but in this case we would have lost the possibility to guide groups individually, use the same signs to guide while entering and exiting a checkpoint, and have temporally dynamic signs.

Platform Features

The research and innovation objective of the production was to combine multiple existing technical components together in order to create a platform that could be used in different kinds of pervasive experiences. The specific objective of this production was to evaluate how different components of the production support storytelling and how manageable they are in real production. The biggest challenge for storytelling was not the lack of features, or missing some particular feature, but the fact that the platform was prepared and designed iteratively while developing the story. Since the goal was to make a more generic platform, some details of the story were compromised for maintaining some degree of genericness in the platform. At this point it is fair to say that the current platform is not practically generic, and cannot be directly used in future productions, but there are some important features in the platform that should be taken further and based on this experience it is much easier to define some key characteristics that the future development iteration in the platform should focus on.

Based on the analysis of this production we can say that important features for generic platform are modular design, web-based interface delivery for global and local interaction, support for both indoor and outdoor navigation and guidance, online configurability of checkpoints and routes, global communication between groups, communication between groups and experience master, and capability to push messages to all groups. MapLens interaction is not critical, but can be replaced with digital maps. Game logic engine and route navigation is very much production dependent, and for example experience with more open ended exploration, without a joint start protocol, or some kind of game scoring, would require entirely different kinds of configurations, guidance configurations and game logic.

Production Practice

Research and developing production practices is significant, since developed practices can make the production significantly more affordable and facilitate more nuanced storytelling techniques. In movie production, there are several tools, such as established script format, call sheets and production breakdowns, for preplanning and coordinating the production. Introduction of production templates and execution of the design phase in an organized manner may compromise structural creativity, but ultimately can allow more specialized roles and efficient operations. A major challenge in our production was the communication between the technical team and concept development. Production group should have an understanding about the whole life-cycle and their role within the life-cycle as well as what is expected in each phase. Production group members should have also well defined roles. In order to make the experience efficient each of the phases should have some kind commonly agreed and established documentation format or templates (for example concept document, script and cue lists, stage designs, route maps). Also, there should be specific team members that focus on testing the experience, and that testing a pervasive experience requires on-site presence and cannot be performed in office reliably.

In order to make pervasive experiences commercially viable, they need to be able to achieve a certain level of development and operational efficiency. Development efficiency is achieved mainly by having a robust and relatively standardized platform as a basis for the production and having professional practices implemented in the pre-operation phases. Operational efficiency is achieved by allowing the production to operate with less crew, with larger scale and more persistently, and by utilizing the participants' own devices. Achieving these goals require significant amount of further development, but this production indicated that such commercial viability could be attained.

Storytelling

Story can take many shapes in a pervasive production such as Lost Lab. The story can be for example based on real-facts (augmenting sites by telling the historical or real site-specific stories), the story perspective can be fictional narrative (characters with conventional storytelling dynamics and participants are merely observers in the story), the story can be focused on introducing context, where participants compete against each other (competitive game), or then for example, the story can be more thematic world or merely a theme, and individual checkpoints deliver unique and relatively independent experiences (which was the case in Lost Lab). It is important to understand how the story can be told in a modular way so that the story can be adapted to different sites and tasks, and how it is linked to the navigation and between group interaction.

In the Lost Lab case the main challenge was to advance storytelling while the production elements, such as site availability and interaction techniques were still under development. For this reason, it was somewhat hard to create a strong storyline that would be critically dependent on certain places or activities. Furthermore, the non-linear orchestration of experience makes implementation of traditional story progress complicated. Different tasks in the checkpoints cannot have fixed casual relationships. In this case we decided to focus the story around the communication agent - the fish Linus - that appeared in different mediums and connected the interaction to the story. As such, the use of an agent proved simple and successful, and the fact that the same agent was in the map, markers, chat and memory wall strengthened the sense of the character significantly. Some of the students were actively asking who Linus was and how it was realized, and many students showed signs of affection for the Linus character in their chat communication. If the overall platform features and restrictions, as well as site-specific capabilities would have been better known early on, it would have been significantly easier to design visual and story-wise elements that cross the boundaries of different mediums. For a successful production, it is critical that storywriters and concept designers have an insightful understanding of the nuances of the story mediums whether they are mobile interface, augmented sites or markers, installations, videos recordings or live video, interactive screens, live actors or audio tracks.

CONCLUSION

The Lost Lab of Professor Millennium was a successful computer-supported pervasive experience. Both the event organizers who hosted the production, partner sites, and students and teachers who participated in the experience, all gave positive or very positive feedback and expected further continuation for the production. This feedback indicates that there is demand and potential for organizing pervasive experiences whether they are focused on educational, site-specific or commercial entertainment.

More detailed analysis of the interaction designs, production practices and technical features of the platform showed that there are many lessons to be learned and details that should be developed further. For example, the communication inside groups appeared to vary significantly between different groups. Understanding the reasons for this variety is a potential further research topic since designing for certain collaboration dynamics can be significant aspect in future production. As a summary of the core lessons learned, we want to first highlight the use of navigation markers as a potential technique in pervasive experience; second, the live chat interaction is technically easy and multi-use technique to engage and inform participants; third, sites and platform restriction should be understood well in advance; fourth, use of AR pointclouds and local interaction are techniques that require more development and integration; and fifth, production practices should have clear templates and pervasive production team should establish roles similarly as movie or game productions.

ACKNOWLEDGEMENTS

This research was funded by EIT ICT Labs Street Smart project. Concept development was led by Professor Dorita Hannah. Research was partnership between Nokia Research Center (Ville-Veikko Mattila, Petri Piippo), Aalto University Helsinki Institute for Information Technology, VTT (Alain Boyer), University of Helsinki, TU Berlin Quality of Interaction groups (Jorg Muller and David Lindlbauer), Forum Virium Helsinki, and University of Padova HTLab (Lucio Gamberini). The production was hosted in the Millennium Prize Pavilion created by Technology Academy of Finland.

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