Kurio: A Museum Guide for Families

**Ron Wakkary, Marek Hatala, Kevin Muise, Karen Tanenbaum, Greg Corness,
Bardia Mohabbati, Jim Budd***

Simon Fraser University
Surrey, BC, Canada
{rwakkary; mhatala; kmuise; ktanenba;
gcorness; mohabbati}@sfu.ca

*Emily Carr University of Art and Design
Vancouver, BC, Canada
jbudd@eciad.ca

ABSTRACT

We discuss three design strategies for improving the quality of social interaction and learning with interactive museum guides: 1) embodied interaction; 2) game-learning; 3) a hybrid system. We used these strategies in our prototype Kurio, which is aimed at supporting families visiting museums. The results of our evaluation show positive implications of implementing the design strategies: closing the social gap, naturalizing technology, and supporting exploration and discovery in learning.

Keywords

Tangible user interface, learning, social interaction, hybrid system, group, families, group interaction, museums

INTRODUCTION

Since the advent of interactive museum guides, museums have garnered growing interest from researchers in human-computer interaction, ubicomp, and interaction design. Interactive museum guides have increased in technical sophistication and capabilities. However, George Hein argues for a constructivist museum that integrates diversity of learning with social interaction: "social interaction allows learners to go beyond their individual experience, to extend their own knowledge and even their ability to learn" [6]. He emphasized the necessity of designing for social interaction given that 80-95 percent of museum visitors are families or small groups [6].

In our research we experienced the challenges and nuances of designing an interactive system that supports social interaction and learning. For example, we developed a tangible and adaptive museum guide known as ec(h)o. The results of the research showed how a tangible user interface (TUI) elicits visitors' playful and curious interactions with museum exhibits [13]. The user interface was a TUI and stereoscopic audio display . This created a highly novel interface that at times engrossed the visitor in exploring how the interface responded to their actions and the environment rather than exploring the exhibit and artifacts.

The question became how to best balance and leverage curiosity and play within a museum guide. On a practical level, social interaction suffered greatly by the need to wear binaural headphones. We also embarked on embodied interaction investigations with a responsive environments prototype for physical gameplay known as socio-ec(h)o [15]. Embodied interaction systems are both tangible and social since they "are manifest in our environment and are incorporated in our everyday activities" [3]. Relevant results from this research included the subtleties of embodied group interaction [14]. While socio-ec(h)o did not take place in a museum setting, it enabled us to extend the research issues of sociality and group collaboration into the current research, Kurio. In Kurio, we focus on social interaction measured by learning in the museum. We employed three design strategies for Kurio: 1) embodied interaction; 2) game-learning; 3) a hybrid system.

Kurio is a museum guide system that supports families and small groups visiting the museum. In Kurio a family imagines themselves as time travelers whose time map is broken and so they are lost in the present time. In order to repair the time map, family members complete a series of challenges that collect information from the museum to fix the map (see Figure 1). The interactive museum guide itself is comprised of a tangible user interface that is distributed over several independent tangibles, a tabletop display, and a PDA (personal digital assistant). We adopted a constructivist-learning model to guide decisions for the interaction, user model, and content.

In this paper, we focus on a description and discussion of the system with particular emphasis on the tangible user interface within a hybrid system and evaluation of the design goals. We will detail technical details, user

Figure 1. Mother and her son with Kurio.

modeling, and museum learning in future papers. This paper begins with related research and we provide a discussion of our design strategies. We analyze and discuss the implications of the results before concluding with a summary of the findings and future research.

TANGIBLE COMPUTING, GROUP MUSEUM GUIDES, AND LEARNING IN MUSEUMS

This system resulted from a breadth of research areas. These include the role of tangible computing, group interaction, and learning in museums.

Tangible User Interfaces for Museums

Tangible user interfaces (TUI) imbue physical artifacts with computational capabilities. Hiroshi Ishii and Brygg Ullmer introduced the notion with the salient phrase of "coupling of bits and atoms" [7]. By their own account, scientific instruments from a museum collection inspired them. They experienced a quality of aesthetics and rich affordances in the oak and brass instruments on display that in their minds have been lost with the advent of computing. It became their aim to "rejoin the richness of physical world with HCI [human-computer interaction]" [8]. Ishii and Ullmer's idea of tangible computing built on earlier work on graspable interfaces [4]. They describe TUIs as the "seamless coupling of everyday graspable objects (e.g. cards, books, models) with digital information that pertains to them" [7].

We explored the rich affordances of physical tangibles as playfulness in a museum in our previously mentioned ec(h)o project. The user interface for ec(h)o was a TUI that coupled a wooden cube with digital navigation and information. In ec(h)o, museum visitors immersed in a responsive soundscape and information about the artifacts on display. Visitors navigated the audio options presented to them by rotating the cube in their palm in a direction that corresponded to the spatial location of the audio they were hearing [13].

In our experience, TUIs have the strong potential to bridge between the virtuality of the interactive museum guide and the physical surroundings of the exhibition. As such, the guide becomes more integral to the physical ecology of the exhibition including artifacts, display systems, and architecture rather than being a separate technology.

Group Museum Guides

In recent years, museum guide research has focused on group museum visits. Sotto Voce, developed by Aoki et al [1] is among the first examples of designing for group interaction. Utilizing PDAs, the system contained an audio sharing application called *eavesdropping* that allowed paired visitors to share audio information related to the exhibit with each other . The social purpose of sharing in Sotto Voce showed a shift from information delivery to a *learning-game* approach to interaction. This is explicit in the CoCicero project implemented in the Marble Museum in Carrera [8]. The CoCicero prototype focused on four types of group activities; (i) *shared listening* – similar to Sotto Voce, (ii) *independent use* – to allow individuals to

not be in a group, (iii) *following* – to allow an individual to lead other members of a group, and (iv) *checking in* – which allows members in a group to communicate while not being together physically. The visit is structured through a series of games, including multiple-choice questions that require visitors to gather clues from the exhibits within the museum. Similarly, the ARCHIE project [9] has developed a learning game for school children that allows visitors to trade virtual cards with museum information to gain points in order to win.

Learning and game interactions like in CoCicero and ARCHIE hold the promise to affect the way in which visitors engage exhibits in museums, and to improve the quality and nature of learning. Yet results and findings from the projects discussed here are either minimal or inconclusive. Nevertheless, these prototypes exist as living proofs and we see how adopting new design strategies can garner design improvements. We see possible gains in the manner and degree of social interaction. Specifically, the nature of the social interaction in these projects is parallel rather than collaborative. Adopting a design that creates opportunities for social collaboration in the process of play extends the learning beyond an individual experience.

In respect to social and physical contexts, the predominant use of a graphical-user interface (GUI) with PDAs and computer kiosks hardens the divide between a virtual and physical experience of the museum visit. We believe that incorporating a TUI approach will significantly increase the contextual social and physical interactions. Additionally, learning and play is carried out in diverse ways and TUIs can be mapped to these differences.

Constructivist Learning in Museums

Learning in museums has long been a focus within of museum studies. The constructivist perspective has emerged as a means to understand how a visitor's learning takes place in the museum [6]. Constructivist theory explains learning as a process where people construct new knowledge based on their current and previous understandings of the world, including their beliefs and past experiences. Within constructivism, learners are encouraged to discover knowledge on their own, which transforms the learner from a passive observer to a "constructor of knowledge" [11]. A visitors' previous knowledge is critical in constructivism and can be supported by helping visitors make connections to the museum experience by providing conceptual access; i.e., the ability for visitors to understand ideas presented, and facilitate meaning making from such ideas. As a means to engage visitors and improve access to information, the constructivist perspective encourages the design of visits that exploit the senses. The constructivist perspective also sees learning as a social activity. Individuals can share their understandings with others of their group [6].

DESIGN STRATEGIES

In establishing the theoretical groundwork for Kurio we published a study of evolving trends in museum guides for

groups and families [16]. Three interrelated design strategies emerged that are directly relevant to the TUI approach in Kurio. These include embodied interaction, game-learning, and hybrid systems.

Embodied interaction

Embodied interaction is a computing paradigm in which tangible computing and social computing are intertwined and incorporated into our everyday environment and activities [3].This notion fits many museum settings very well given the sociality of museums and on the encouragement of curious and playful interaction with physical objects and interactives. We discussed how in ec(h)o, tangibility supports embodied actions like walking and gesturing as integral to the experience.

Game-learning

Gameplay refers to the quality of the mechanics or play in a game. We observed that the idea of gameplay in the service of learning can be applied to interaction with museum guides. Games and play are used in the museum as an interaction convention that creates a set of expectations for how visitors learn and explore. Game interaction supports learning in ways that connect to constructivist exploration and discovery. Additionally, games and learning models can coordinate and structure interaction and learning activities for families and groups while visiting museums.

Hybrid systems

Past interactive museum guides adopted a mobile computing approach utilizing graphical user interfaces (GUI) on handheld PDAs. The emergence of tangibility offers an approach different from mobile computing. The user interface demands can be distributed across different tangible devices that can be simple, designed to work together, and customized to a particular setting and activity. TUIs are reliant on context as part of their interaction, and this reliance creates social opportunities in shared contexts. We believe this emergent tangibility model better supports group and family interaction in museums. Having said that, group and game interaction requires coordination and collaboration. Here a PDA or shared display with a GUI can serve a key role in coordinating different members of the group and family during a museum visit. Additionally, a GUI provides a virtual collaborative space that in game interaction can represent the shared state of the game and provide a collaborative space to communicate and help each other. Hence, we see PDA/GUIs providing shared virtual space for coordination and collaboration. Considering all of this, we came to the conclusion that hybrid systems, incorporating TUIs and GUIs, best support the type of embodied interaction of tangible and social computing that we've been discussing. A hybrid system might include tangible devices and shared displays in the form of a PDA and or tabletop computer. This is exactly the approach we have taken in Kurio.

KURIO – DESCRIPTION OF THE PROTOTYPE SYSTEM

Kurio is a hybrid system comprised of a set of tangible computing devices, a PDA, and a tabletop display. We used

**Figure 2. Tangibles from left to right:** *listener, pointer, reader.*

a game-learning approach to motivate and structure the families' visits. In addition, we centralized processing across the system in a reasoning service that included a rules-based reasoning engine.

Time travel game

We developed a narrative and challenge game for the interaction structure of the system and visit. In the game, families played time travelers stranded in present time because of a broken time map for their time machine. In order to repair their time map, the travelers needed to gather information about their current location and time. The onboard computer, Kurio, aided them by providing missions that included challenges to gather knowledge required for the map. The missions were topically organized and directed families to particular parts of the museum. Three missions needed to be successfully carried out in order to complete and fix the time map. Each challenge asked family members to find historical information from within the museum using tangibles. Challenges were assigned to each family member concurrently, allowing them to work collaboratively or independently. One family member acted as the coordinator and supporter of the group's actions with a PDA application, in lieu of receiving a challenge.

Kurio hybrid system

The main component of the hybrid system is a set of tangible computing devices. We aimed for the technology to become part of the game narrative, and as such the tangibles were designed as tools that expressed the storyline and invite playful interactions. In this round we tested three tangibles (see Figure 2). The first is known as the *pointer*. It is reminiscent of a flashlight and is used by pointing at museum artifacts you want to select. The second tangible is the *reader* that is shaped like a magnifying glass and is used for collecting text from didactic displays. The third tool is the *listener* for hearing audio files in different locations in the exhibition space. It resembles an old portable AM radio or walkie-talkie. In each case, the interaction involves a color change signaling that the tangible has sensed an item to be selected, a button for selecting, and vibration or color feedback confirming the
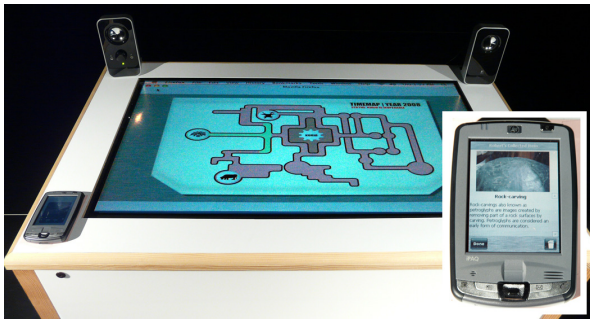
Figure 3. Tabletop displaying the time map and detail of the *monitor* (inset).

selection. The tangibles serve as the means of collecting information and knowledge.

A PDA was used to coordinate family members within a mission and support them in completing missions and challenges. We referred to the PDA and the application as the *monitor* (see Figure 3). The PDA application monitored each family member's progress with challenges and assigned new challenges and tangibles. The application displayed the items collected by the tangibles, e.g. a museum artifact or text from a didactic display, as well as explanatory information about the item. After reviewing this information, the family members could decide whether that item should be kept or discarded, based on the challenge and relay who helped the family member with a particular challenge. The application provided information for assessing learning levels and challenges in which an answer is not definitive, by asking the family member with the *monitor* to evaluate the information collected.

A tabletop display was used to provide families with awareness of the game state, i.e. how far along and successful they were in completing missions, the time map, and challenges (see Figure 3). In addition, the tabletop provided reward videos and additional information to guide the learning process at the end of each mission. The interaction with the tabletop was kept simple. When the family returned to the table to gauge their progress, the information collected would be graphically displayed on the tabletop along with the time map. Family members could review the information collected to see if it met the challenge or, if not, what the best answers were. After completing a mission the families chose a new mission from the time map.

A learning system

Learning theory informed the interaction structure and the user model. A full discussion on learning and in particular the user model requires a detailed treatment of its own and therefore is limited to an overview in this paper. As a basis for the interaction structure we used a variant of Constructivism known as the learning cycle [5]. The learning cycle comprises three phases: *exploration*, *invention* and *discovery*. In the *exploration* phase, learners are engaged in solving a task that allows a variety of strategies, yet specific enough to give them direction. This

is manifest in the challenges in the Kurio game. The *invention* phase uses the information from the *exploration* phase to introduce concepts and any vocabulary associated with their experience. In Kurio, we employed reward videos at the end of each mission to introduce new concepts and vocabulary. In the final phase, *discovery*, the new concepts would be used by learners in solving new tasks, which in Kurio would be new challenges in the next mission. For example, visitors would be introduced to the concept of "community" after completing challenges in a mission related to First Nations Peoples. The concept of community is required in completing the next mission, which might focus on the ties between forestry and the growth of the community, as an exploration of the role of industry.

We employed a rule-based reasoning engine to support the learning cycle and to dynamically map each family member's learning level with appropriate challenges. The reasoning engine also matched learning levels, challenges and tangibles in ways that best supported the visitor according to our model and supported their learning progression. The learning model we used is Bloom's taxonomy, which outlines a hierarchy of learning stages including *Remember, Understand, Analyze, Apply, Create,* and *Evaluate* [2]. The reasoning engine relied on information provided by the reviews of challenges conducted with the *monitor*, information on who helped with the challenge, the knowledge as to whether or not the task was completed correctly, and the number and level of challenges completed by an individual.

Technical overview

We deployed a client/server architecture in which the central reasoning service communicated with the tangibles, PDA, and tabletop display through a bi-directional asynchronous UDP protocol across a Wi-Fi network. Data and instructions were encoded using an XML-based message exchange protocol.

The processing on the tangibles was done on a Gumstix prototyping board programmed in Python and running a Linux OS running on a 400mHz processor and a Mini-Arduino using an Atmega168 microprocessor and the Arduino programming language. These two processors were networked together using a Universal Asynchronous Receiver/Transmitter (UART) connection. Multi-colored LEDs were used for confirmation and feedback. The tangibles identified objects in two ways depending on the device. The *pointer* and *listener* used IR sensors that detected IR beacons placed next to museum artifacts. The *reader* incorporated an embedded RFID reader that read RFID tags we encased in a small icon that was fastened to the didactics in the museum.

The *monitor* was an HP iPAQ running MS Windows Mobile 5.0. The tabletop display was designed by the team [10]. Both the *monitor* and *tabletop* applications were developed in mobile and desktop versions of Adobe Flash. The rule-based reasoning engine was implemented in Jess

(embedded Java reasoning engine). The rules operated on the ontological conceptual model in OWL (Ontology Web Language) representing the learning and user model, tasks, game, and artifacts.

USER STUDY

In our evaluation, families tested Kurio in a local history museum. The number of participants was 25 parents and children, or 8 families. The family sizes ranged from 2 to 4 and in 2 cases a family friend joined the group. There were 15 children between the ages of 7–12: 8 boys, 7 girls. There were 2 children between the ages of 13-17: 1 boy, 1 girl. And there were 8 parents (7 mothers, 1 father) ranging in age from 24 to 57. The families were recruited from local schools by way of mailing lists and notices circulated at the schools. A user session consisted of the families completing the game by repairing the time map (on average 45 minutes). This was preceded by a short tutorial on the system and a brief interview and questionnaire on previous experiences with museums and technologies. Following the session, participants completed questionnaires and a semi-structured interview. The sessions were both video taped and audio recorded. Lastly, 2-4 weeks after the study and on a volunteer basis, families conducted self-administered interviews based on a script we provided. We received back interviews from 6 of the 8 families.

Since our study involved children, we developed two questionnaires. The first was for children 7-12 years old, and the second was for parents and children older than 13

Question		AVG	SD
A	Did you have fun with Kurio?	3.73	0.96
B	Was Kurio easy or hard to use?	3.33	1.05
C	Were the tasks given by Kurio easy or hard?	3.20	0.77
D	Were you excited or bored about the next task given to you by Kurio?	3.20	0.86
E	Was Kurio helpful in learning about things in the museum?	3.53	0.74
F	Was Kurio fun to use with your family?	3.53	0.92
G	Is using Kurio a good way to visit a museum?	4.00	0.68

Table 1. Smiley-o-meter section of questionnaire for 7-12 yrs old participants answered on a scale of 1-5, 5 being best; n=15.

	Fun Sorter				Again-Again	
	H. Part of Kurio that was the most fun?		**I.** Part of Kurio that was easiest to use?		**J.** Would you use these parts of Kurio again?	
	AVG	SD	AVG	SD	AVG	SD
Pointer(n=15)	3.58	0.83	3.67	1.10	4.57	0.45
Listener(n=8)	3.39	1.11	2.81	1.16	3.94	0.92
Reader(n=9)	3.47	0.97	3.63	0.99	4.43	0.49
Monitor(n=11)	3.98	1.25	3.18	1.37	4.27	0.76
Table(n=15)	3.58	0.99	4.33	0.74	3.65	0.92

Table 2. Fun sorter and Again-Again sections of questionnaire for 7-12 year olds answered on a scale of 1-5, 5 being best.

	Question	AVG	SD
A.1	How much fun was Kurio?	3.90	0.74
A.2	How confident do you feel about using Kurio after the evaluation?	4.22	1.09
A.3	Did Kurio require a large effort to learn?	3.30	1.42
A.4	Did your attitude toward Kurio become more or less positive as the evaluation progressed?	4.00	1.41
B.1	How well did Kurio help you in exploring the museum in ways that interested you	3.70	0.95
B.2	How well did Kurio let you enjoy the museum with your family and or friends	3.89	1.05
B.3	How well did Kurio help you learn about the museum exhibition and the artefacts	3.80	0.92
B.4	How well did Kurio let you learn together with your family and or friends about the museum exhibition and the artifacts	3.89	1.17
C.1	How well does Kurio fit in with the exhibition environment?	3.90	0.88
C.2	How integral a part did Kurio feel with the exhibition?	3.56	1.24
C.3	Did using an interactive system like Kurio benefit your experience of the museum exhibition?	4.33	0.71
C.4	How well does an interactive system like Kurio fit with how your family would like to visit museums similar to the Surrey Museum?	4.50	0.71
C.5	If you were the monitor (used the PDA), how much do you feel you helped others in exploring the museum?	4.11	0.78
D.1	Is using Kurio a good way to visit the museum?	4.50	0.53
D.2	How easy was Kurio to use?	3.60	0.97
D.3	Were the tasks Kurio assigned helpful in exploring and learning in the museum?	4.00	0.47
D.4	How interested were you to get the next task assigned?	4.10	0.57
D.5	If you or a member of the family completed a task successfully, how difficult was the next task?	3.78	1.39
D.6	If you or a member of the family did not complete a task successfully, how difficult was the next task?	4.00	0.89
E.1	How much did you discover that you did not know previously?	3.90	0.74
E.2	How much more did you learn about things you already knew?	3.33	1.22
E.3	How much more curious did the museum experience make you?	4.20	0.42
E.4	How exciting was it to learn?	4.00	0.47
E.5	Some of what I learned will be useful to me?	3.00	1.41

Table 3. Questionnaire for 13 year old and older participants answered on a scale of 1-5, 5 being best; n=10.

years old. We based the 7-12 year old questionnaire on Read and MacFarlane's [12] "Fun Toolkit." Based on constructivist theory that sees learning as an ongoing process, evident through the learning's integration into everyday life, the self-administered interviews were conducted by participants 2-4 weeks after the session. We also believed that the familial setting of the self-administered interview would elicit a greater degree of authentic responses.

DATA ANALYSIS

The data was gathered from observations, audio and video recordings, questionnaires, interviews, and the self-administered follow-up interviews.

Questionnaire data

Questionnaire for 7-12 year old participants

Children from 7-12 years old completed a questionnaire based on the Fun Toolkit [14]. This comprised of three sections. Table 1 shows the average response to Likert scale questions using smiley faces that were converted to a scale of 1-5, with 5 being best. The questions assessed general perceptions of use, fit with family, and benefits in respect to learning and enjoyment.

Table 2 shows data from the two remaining sections of the questionnaire that used two techniques for assessing the different UI components of the system. The fun sorter (questions H, I) asked participants to place stickers of images of the system components on a scale from best to worst. These placements were converted to a scale of 1-5, with 5 being best. Again-Again asked participants to rate each component on whether they would like to use them again. The children could respond by marking boxes labeled "Yes-Maybe-No". This was converted to a numerical scale and scaled to 1-5, with 5 being best. Not all children used all parts of the system so the number of respondents varies. In the case of the *monitor*, the degree of experience with the PDA varied. For example, a small number of children were assigned the role of *monitor*, which meant directly using the PDA and coordinating family members, however even those who did not use it directly but interacted with the *monitor* while using tangibles felt they "used" the *monitor* and therefore rated it.

Questionnaire for 13 years old and older participants

The second questionnaire was given to parents (n=8) and children 13 years old and older (n=2). The questionnaire included 24 Likert scale questions from 1-5, with 5 being best. The results are in Table 3. It also included 7 structured questions requiring written answers.

Analysis

Overall impressions

The overall impressions of the experience and Kurio were positive. In Table 1, questions A to C show high scores with a consistently low variance between answers. In Table 3, questions A.1 to A.4, parents and older children scored Kurio even higher, however the variance increased slightly reflecting individual preferences. In the semi-structured interviews, a child responded: "*I feel that like I absorbed the information, instead of just reading and skimming over it and leaving...you actually had to look at it, and it was more fun to read it and look at it, than to just read it and be like "oh this is interesting" and leave.*"

In one exchange a child remarked: "*you can actually do things, like you just don't look at things or watch movies or something, but you find stuff...*" The parent responded: "*Exactly, the physicality of it because it's interactive...the fact that all the senses were, you know, you could maybe move, gesture, listen, read, point, you know...there was physical stuff.*"

Fit with the museum, family, and learning

Kurio rated positively in respect to questions on the fit with the museum, fit with the family, and support of learning. In table 1, questions E to G, the 7-12 year old participants scored the system highly with scores between 3.54 and 4.00, and with a low variance. The older children and parents rated the system similarly in questions B.1 to B.4 and C.1 to C.5 (see Table 3). Highly encouraging was the response to C.3 to C.5 (see Table 3) that asked to rate the benefits of the experience, the fit with the family, and whether the system helped them help others. In these questions the scores rated from 4.11 to 4.50. In answers to the structured question about Kurio's fit with the family, participants commented that "*there was something for everyone,*" referring to the different tangibles, and that it allowed family members to "*assist each other*" and that they particularly liked how the roles changed, i.e. switching of the *monitor* roles and tangibles.

Tangibles and other UI components

The questionnaire for children 7-12 probed particular impressions of different UI aspects of Kurio. This group more fully used the range of tangibles than the adults. The questions and results can be found in Table 2. The components scored highly, especially the *pointer*, *reader*, and *monitor*, supporting a hybrid TUI/GUI strategy. The *listener* scored lower and we soon realized that selection of audio sound clips created a UI problem that caused difficulty for some (it was the only tangible with multiple buttons). In the structured questions, many commented on how the components were fun and improved the experience. However, particular concerns were raised about some of the content in terms of language level and correspondence with what was actually in the museum. Concerns were raised of the need to constantly display the challenges, and some had issues with the integration of the RFID chips on the didactics. Lastly, one parent wondered if every tangible should have a built in graphical display, and another wondered if an all-in-one tangible that incorporated the different capabilities together would be an improvement.

Social Interaction and Learning

We separated the analysis of our higher-level goals of social interaction and learning from the questionnaire and interview data. This analysis requires a greater degree of

Figure 4. Mother and her son "pause" to discuss a challenge (left); boy explaining to his sister what she needs in order to complete a challenge (right).

synthesis of data points that include the above plus observations based on video and audio recordings, and the follow-up self-administered interviews.

Social interaction

In light of constructivism it is difficult to discuss social interaction separate from learning. Many of the observations we make here we will reference again below. In respect to the questionnaires and interviews, qualities of social interaction are not made explicit unless they are hindered. Conversely, the few explicit remarks that we've cited show that the assumption that families should be able to interact socially despite the demands of the technology was met. In the sessions, we observed constant interactions between parents and children, as they were able to momentarily ignore the technology and collaboratively reflect on the challenge and the museum artifacts. This offered multiple opportunities for parents to support their children in explaining or contextualizing problems in solving the game (see Figure 4).

In one example, a child is tasked with a challenge in which the spinning wheel is the answer. She cannot solve the challenge. Her mother reminds her of how her grandmother knitted with yarn. In discussion they recall that stores selling yarn may not have existed in the past and "*you had to raise sheep, you cut the sheep for the wool, and you had to spin the sheep's wool into yarn.*" In another example, social interaction is peer based rather than parental. Here, a twelve-year-old boy is the *monitor* and so has the PDA. He becomes a hub for the other children. In one instance, the *monitor* lets the boy know that his younger sister needs to find a new object, "*Ella…it says you have…*" The two share the screen of the PDA (see Figure 4). Soon after, the boy finds his friend and shows him the screen. He tells his friend what he should be looking for.

Despite this example, we also observed instances when coordination issues overwhelmed the family member with the *monitor*. This naturally increased with the size of the family.

Learning

Our assessment of learning with Kurio is based on Hein's principles of the constructivist museum [6] that we discussed earlier. A first principle is that the constructivist approach rests on the idea that knowledge is constructed in

the mind of the learner. This is evidenced in the use of previous knowledge, experiences, or a personal motivation and reward for learning. In the example of the spinning wheel, the previous experience of the daughter's grandmother provided a scaffold for the learning. In one interview, a child explained how the visit made her think about what she learned at school in her "*First Nations Study Group.*" In another example, a boy was convinced that each challenge successfully done was going to help him at school with his grades.

A second principle is that learning needs to be active and engaging. We found in the data from the questionnaires, interviews, and in the follow-up interviews that Kurio was engaging and fun. Fun in this sense is not trivial but is a sign of a meaningful engagement. For example, in a follow-up interview, a child stated that Kurio provided him with the ability to "do things," and express that the museum experience was fun. In the same interview, a sibling offered that the question and challenge structure was engaging. In another example, a child explained how he had to find the yarn spinner (a similar challenge to the example above but a different participant). Although he could not remember what the yarn spinner was called, he did understand that it was used to make yarn. He went on to describe it and his related thoughts in his own terms and based on what interested him and remarked on how thinking of the past was "*weird…but had an awesome feeling too.*"

The third principle is that a visit should be physically, socially and intellectually accessible, and if possible, exploit all senses. In our earlier analysis we cited how a parent felt Kurio engaged the senses. Her son told us how he would tell his friends that "you can actually do things" and not just "look at things or watch movies." In another example, the family discussed how they normally visit the museum, and how Kurio was very different. They expressed concerns that they were constrained; yet, they saw how it made new things accessible. The mother remarked: "*it exposes you to a variety of things that you might not otherwise look at. And he probably read things that he wouldn't have read otherwise.*"

DISCUSSION

Many technical and incremental design issues arose from our testing that we are addressing in an updated version. These include UI controls for the *listener*, in which we need to simplify the interaction for sampling the audio file; improve in the content writing and the ability to review tasks and see correct answers at the tabletop display and with the *monitor*; and better align text information on displays with the RFID tags. Given the ecological nature of the study it is difficult to make definitive claims, however, we feel that the results support the intended goals of social interaction and learning. Our design strategies of embodied interaction, game-learning, and hybrid systems hold up well under the scrutiny of the analysis.

We see three positive implications in adopting the design strategies we pursued:

Closing the social gap: our results support the finding that Kurio achieved a level of quality of social interaction that closes the social gap evident in most interactive museum guides. The hybrid system allowed for a distributed involvement that was greater than sharing by encouraging complimentary but diverse involvement of family members. The game-learning approach structured activities as both collaborative actions and collaborative reflections. The embodied nature of the TUIs allowed for the interplay between social and physical context as one might normally assume in a museum regardless of the technology imposition. We do note that the coordination issues of larger families, e.g. four can be problematic for the individual in the *monitor* role.

Naturalizing technology: The TUIs helped adapt the technology to the everyday environment of the museum that includes physical interactives, exhibit displays and artifacts. By incorporating the richness of the museum environment we can leverage the qualities of social and embodied interaction that makes museums a valuable learning environment. The learning-game interaction contributed to naturalizing technology by rendering the devices on a symbolic and token level that appealed to the imagination as well.

Shift to exploration and discovery: Interactive museum guides in the past focused on information access and richness. The move toward embodied interaction and game interactions created the opportunity to design learning activities with interactive technology that are based on personal exploration and discovery rather than information retrieval and retention. This motivated the learning, and created scaffolding for social and collaborative efforts.

CONCLUSION

In conclusion, the qualitative findings from the study data support the claim that Kurio addressed aspects of social interaction and learning for families in museums. The findings support the adoption of the design strategies of hybrid systems (TUIs and GUIs), embodied interaction, and game-learning in designing museum guides for families.

ACKNOWLEDGMENTS

REFERENCES

1. Aoki, P.M., Grinter, R.E., Hurst, A., Szymanski, M.H., Thornton, J.D. and Woodruff, A., Sotto Voce: Exploring the interplay of conversation and mobile audio spaces. *In Proc. CHI 2002*, ACM Publications (2002), 431-438.

2. Bloom, B.S. Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain David McKay Co Inc., New York, 1956

3. Dourish, P. Where the action is: the foundations of embodied interaction. MIT Press, Cambridge, Mass., 2001.

4. Fitzmaurice, G.W., Ishii, H. and Buxton, W.A.S., Bricks: laying the foundations for graspable user interfaces. *In Proc. CHI 1995*, ACM Press (1995), 442-449.

5. Fuller, G.R. "Don't tell me, I'll find out" Robert Karplus – a science education pioneer. Journal of Science Education and Technology, 12, 4 (2003), 359-369.

6. Hein, G. Learning in the Museum. Routledge, Cambridge, 1998.

7. Ishii, H. and Ullmer, B., Tangible Bits: towards Seamless Interfaces between People, Bits and Atoms. *In Proc. CHI 1997*, ACM Press (1997), 234-241.

8. Laurillau, Y. and Paternò, F., CoCicero: un système interactif pour la visite collaborative de musée sur support mobile. *In Proc. AFHIM 2004*, ACM Press (2004), 101-108.

9. Loon, H.V., Gabriëls, K., Luyten, K., Teunkens, D., Robert, K. and Coninx, K., Supporting Social Interaction: A Collaborative Trading Game On PDA. *In Proc. M&W 2007*, Archives & Museum Informatics (2007).

10. Motamedi, N., HD touch: multi-touch and object sensing on a high definition LCD TV. *In Ext Abstracts CHI 2008* ACM Press (2008), 3069-3074.

11. Naismith, L., Lonsdale, P., Vavoula, G. and Sharples, M. Literature Review in Mobile Technologies and Learning, Report 11 NESTA Futurelab Series, 2004

12. Read, J.C. and MacFarlane, S., Using the Fun Toolkit and Other Survey Methods to Gather Opinions in Child Computer Interaction. *In Proc. IDC 2006*, ACM Press (2006), 81-88.

13. Wakkary, R. and Hatala, M. Situated Play in a Tangible Interface and Adaptive Audio Museum Guide. Journal of Personal and Ubiquitous Computing, 11, 3 (2007), 171-191.

14. Wakkary, R., Hatala, M., Jiang, Y., Droumeva, M. and Hosseini, M. Making sense of group interaction in an ambient intelligent environment for physical play *In Proc. TEI 2008*, ACM Press (2008), 179-186.

15. Wakkary, R., Hatala, M., Lovell, R. and Droumeva, M., An Ambient Intelligence Platform for Physical Play. *In Proc ACM Multimedia 2005*, ACM Press (2005), 764-773.

16. Wakkary, R., Muise, K., Tanenbaum, K., Hatala, M. and Kornfeld, L. Situating Approaches to Interactive Museum Guides. Museum Management and Curatorship, 23, 4 (2008), 367-383.