Experience Structuring Factors Affecting Learning in Family Visits to Museums

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Abstract. This paper describes the design and evaluation of an adaptive museum guide for families. In the Kurio system, a mixture of embedded and tangible technology imbues the museum space with additional support for learning and interaction, accessible via tangible user interfaces. Families engage in an educational game where family members are assigned individual challenges and their progress is monitored and coordinated by the family member with a PDA. After each round of challenges, the family returns to a tabletop display to review their progress. In this paper we present the overall evaluation result of Kurio and, using the model discovery approach, we determine which experience structuring factors have a substantial influence on the learning experience.

Keywords: Social interaction, learning, user modeling, tangible user interface, museums guides, family.

1 Introduction

The Kurio system facilitates social interaction in the museum by giving museum visitors personalized tasks and unique tangible user interfaces that they use in coordination with other family members to complete group activities. A mixture of embedded and tangible technology as part of an educational game facilitates novel learning and interaction opportunities in the museum space. By modeling both individuals and the group, an adaptive reasoning engine attempts to intelligently guide the flow of the visit to suit members on a personal as well as aggregate level. The main goal of the system is to select tasks for the individual family members that are the most appropriate for their knowledge level and will contribute the most to their experience and learning about the museum.

The Kurio system extends our own prior research on the use of adaptivity and tangible user interfaces within a museum environment in a project known as ec(h)o [1, 2]. Museums and cultural heritage spaces have provided fertile ground for a number of projects investigating how to engage people with electronic guides or audio tours aimed at augmented information retrieval, novel museum visit interactions, and new approaches to learning in museums.

1.1 Learning in the Museum

Family groups comprise more than half of all visitors to museums [3]. One common interaction pattern is that in many groups, individual members will go off to explore the museum on their own for periods of time, and then return to the group and share what they have found [3]. This return-and-share strategy is frequently enacted by younger family members exploring and then coming back to talk with a member of an older generation. Several studies have noted that parents tend to informally take on the role of a teacher within the museum, guiding the learning of the children in the group, often in subtle, almost unnoticeable ways. Hilke's 1989 study of family behaviour in the museum revealed that children and adults alike spent a lot of time exploring their own interests, with children taking the lead slightly more than adults [4]. In another study, discussion with adult family members revealed that they often cited their children as a reason for spending time in the museum [5]. However, Hilke's study showed that if parents do undertake a teaching role for their children, they do it "with such subtlety that the spontaneous pursuit of individual agendas to learn and share was not visibly disrupted" [4]. Woodruff et al. in their study of the use of an electronic guidebook, noted that dyads of parent-child tended to share a guide, whereas adult dyads took individual guides. In the parent-child groups, the children controlled the guide and made the choices for the most part, with the parents looking on and offering suggestions [6].

Some recent museum systems have taken this group dynamic into account and created guides that are meant to be shared. The Sotto Voce system by Aoki et al [7] is one of the first museum guide system to actively support group interaction. Sotto Voce contains an audio sharing application called eavesdropping that allows paired visitors to share audio information related to the exhibit with each other via PDA devices. This system allows for open-ended interaction, as visitors are free to follow whatever path they like and share as little or as much as they want to. The CoCicero project implemented in the Marble Museum in Carrera [8] is a group guide system which introduces a goal state that encourages group interaction. 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. Each member of the group has a personal digital assistant (PDA) on which they can complete individual games or answer questions that contribute to the completion of a shared puzzle. There are also stationary large displays in the space, which can be shared by more than one person instead of using the PDAs. A final example of a museum system addressing the issue of social interaction is the ARCHIE system at the Gallo-Romano Museum in Belgium [9]. ARCHIE is a PDA-based trading game that invites small groups to play a game that helps them learn about social differentiation and exchange in West Europe around the year 825 BC. Within each group, one person is designated as the "leader" and the others are "farmers". By exploring the museum and answering multiple choice questions, the farmers earn resources like cattle and sheep while the leader attempts to balance goods across the farmers and trade for other resources. Each of these systems encourages the kind of group interaction that can support the natural learning behaviors of families in the museum.

1.2 User Modeling for Groups

While the systems described above encourage family members to interact and share information, none include any sort of adaptive component to tailor the situation to a particular group. Many individual guide systems have intelligent components containing user models which can adapt the system's responses to suit the user better, allowing them to accomplish their task more efficiently, steering them in the right direction if they are unsure how to proceed, or recommending things that the user is likely to want or need based on past experience. To do this, the system might extract assumptions about the user that are not explicit in the individual's own data or use the data to make predictions about the user's likely preferences or future actions. This task becomes even more difficult when dealing with one user but a group of users. While there are no other museum systems that contain an adaptive component for groups, there are a number of web or desktop based systems that look at group modelling with a learning focus.

Suebnukarn & Haddawy [10] have devised a system for overseeing group problem solving in the medical domain. The group model monitors student progress in reasoning from a patient's symptoms to a cause; when the students become stuck or miss important steps, the system gives hints and clues to nudge them back onto track. Similarly, Harrar et al [11] are developing a cognitive tutor to monitor direct online collaboration between student dyads. Although their system is not fully implemented yet, they have presented preliminary work that involves studying interactions between student pairs and modeling the types of reasoning paths frequently seen in actual problem solving behaviour. In the same domain, but with a different focus, Read et al [12] present a language tutor where students have individual models which capture their linguistic abilities and background. When collaborative tasks are undertaken, a group model is created to represent that particular collaboration. The effectiveness of group interaction is assessed by a human expert, and the rating of the group work as well as the model created is associated with each individual user after the group dissolves. Knowledge of previous group formations and their efficacy is used to assign users to groups in future collaborations. Unlike the other two tutor systems, Read et al does not include the ability for the group model to supervise and direct the student activities. Their model is used primarily to achieve optimal group formation rather than being actively involved in shaping the group's behaviour once formed. Alfonseca et al [13] studied the effect of student learning styles on collaboration in an online learning system. The system has an adaptive component which recommends activities based on each individual's learning style and knowledge level. When the activities recommended are collaborative tasks, there is an option to have the system recommend a group to work together based on their combination of learning styles. While the group itself is not modeled or adapted to during the course of the collaboration, the recommendations for grouping arose out of the individual user models. The systems described above take a number of different approaches to modeling learning, but most have detailed individual models that capture information about a single person's knowledge, skill level, or cognitive capacity, while the group model exists to find optimal combinations of group members or guide group performance.

2 The Kurio System

In Kurio, a family imagines themselves as time travelers from the future whose time map is broken, stranding them in the present. Family members complete a series of challenges that encourage them to learn certain concepts from the museum in order to fix the map and continue their time travels. The interactive guide itself is comprised of a tangible user interface that is distributed over several tangibles with different functions, a tabletop display, and a PDA. A constructivist-learning model was used to guide decisions for the interaction, user model, and system content. A discussion of the design strategies used in developing the system can be found in [14].

2.1 Technical Details

The Kurio system has four main components: the handheld tangibles, a tabletop system, a PDA, and a server containing the reasoning engine. Fig. 1 shows the information that is exchanged between all of these parts of the system. The tangibles, PDA and table system all communicate wirelessly with the server using an XML-based message exchange protocol.

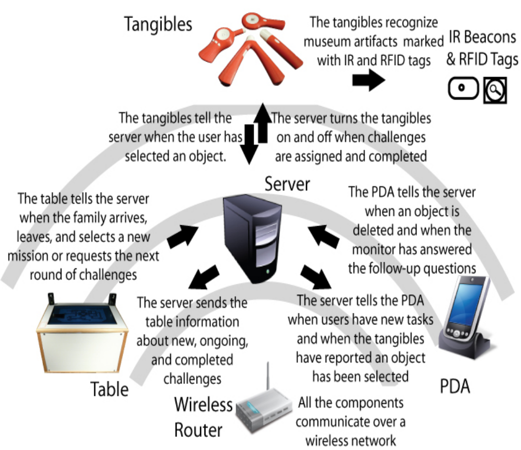

Fig. 1. The information flow between Kurio system components

The tangible user interfaces or tangibles are custom designed devices with shells produced on a 3D printer. Inside the shells, the processing is done on a Gumstix prototyping board programmed in Python and running a Linux OS and a Mini-Arduino using the Arduino programming language. Multi-colored light emitting diodes (LEDs) were used for confirmation and feedback to the user. The tangibles identified objects in two ways depending on the device. The pointer, listener, and finder used infra-red (IR) sensors that detected IR beacons placed next to museum artifacts. The reader incorporated an embedded radio frequency identification (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 our team and was connected to a Mac Mini. 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 Web Ontology Language (OWL) representing the learning and user models, challenges, game, and artifacts.

2.2 Example Experience

The flow of the Kurio experience is best described by narrating a prototypical account of a family's interaction. The family begins at the tabletop display, where they are introduced to the time-travel narrative of the game and view a video that introduces each of the tangible user interfaces and the PDA. From there, they view the broken time map and select the first *mission*. There are five possible missions, each of which relate to a specific exhibit area, and each family needs to complete three of the five possible missions to fix the time map. When the first mission is selected, the table sends a message to the server and receives back the first set of individual *challenges*. The server is preset with each member's age and name, allowing it to select the appropriate starting level of the challenges. For example, Kim, age 9, has been assigned a challenge with the listener, while Simon, age 7, has a pointer challenge. Each tangible has a specific function in terms of the information it can access: the pointer selects museum artifacts, the reader selects text from museum didactics, the listener plays audio clips in different locations in the exhibit, and the finder provides directional information for particular exhibits. When tangibles are assigned to each child, the tangibles glow green, indicating that they are ready to be used. The children's mother, Sheila, is asked to collaborate with and help her children for the duration of the first mission. She is given the PDA and her role is to coordinate and facilitate the completion of the challenges by the other group members.

Once everyone has been assigned a role for the mission, the family leaves the table and heads out into the museum space. Simon's challenge asks him to "Find objects in the First Nations area made out of parts of animal." As he walks through the First Nation's exhibit, he notices that the tip of the pointer glows blue instead of green when he points at certain objects. When he presses the button on the pointer, the PDA that Sheila is carrying chimes and displays the object that Simon has just picked up. Together, she and Simon can look at a photo and short description of the object and decide whether or not it is the answer he was looking for. They can also call up Simon's question if he's forgotten what it is. Simon decides he wants to select something different, so Sheila deletes the object from the PDA and Simon's pointer is re-activated.

Meanwhile, Kim has continued exploring and discovers that her listener turns blue at the tip when she stands near the canoe. She plays the listener by pressing a button on the tangible. She hears a sound clip describing how First Nations fishermen would hunt using nets and canoes. She selects this clip as the answer to her challenge, and then goes over to Sheila to see if her mom agrees with her decision. They both think it is the correct answer, so Sheila selects the “review” button at the bottom of Kim’s challenge screen. She answers two quick questions about how difficult Kim found the question and whether anyone helped her answer it. Kim is assigned a new challenge and goes back to the table to exchange the listener device for the reader.

Kim and Simon continue doing challenges until the monitor informs them that they should return to the table. Once there, they can view the results of their work. Challenges that were completed successfully are displayed on one side of the screen while objects that are incorrect are displayed on another, along with the correct answer. The family can review this information and discuss their progress. Next, the system either assigns a new round for the same mission, or moves them on to the selection of the next mission; depending on how much time they have spent so far. At the end of each mission, they are able to view a short “reward” video that gives them more information about the area of the museum they just finished exploring. When the next mission begins, the monitor is switched over to Kim and Sheila gets to try out the tangibles. In this manner, they complete three missions, fix their time machine, and are able to continue on to the future.

3 Modeling Family and Its Members

The above scenario gives a flavor of how the Kurio experience progresses. The reasoning engine on the server is what guides the course of the game, keeping track of everything that happens and making decisions based on that information. We had two main goals in mind in terms of how to customize the game experience for each family:

1. To find the appropriate challenge level for each individual, and
2. To manage the length of the mission rounds to suit the pace of the group.

At its core, the reasoning engine is a rules-based expert recommender system, supported by a knowledge base consisting of an ontology of the available missions and challenges. A set of individual models as well as group model is maintained throughout the course of each family’s interaction with Kurio. Because of space limitation here we provide only an overview of user and group models.

3.1 Individual Models

The individual models consist of some basic demographic information (name, age, family name) and a set of values for specific learning-related skills. To structure the learning model, we used Bloom’s taxonomy [15], which progresses through 6 levels of learning: Remember, Understand, Apply, Analyze, Create and Evaluate. Each individual challenge is categorized according to which level of the taxonomy it relies on most. The age of the individual participant is used to set the starting values for the skills. When a new challenge is to be assigned, the reasoning engine ranks all possible challenges and chooses from amongst the ones that are the best fit. Three criteria are used to automatically rule out certain challenges: current mission, device availability, and age.

1. *Current mission:* If the challenge is not part of the current mission, then it is not considered for assignment. The missions have between 18-24 challenges in total.
2. *Tangible user interface availability:* Any challenges requiring a tangible that is already in use is discarded from the pool of candidates. In each mission, there are between 3-7 challenges for each device.
3. *Age:* The listener device was more difficult to use than the others, both in terms of interface and in terms of the cognitive requirement to listen to and extract information from the audio. Therefore, an age limit was set so that children under the age of 9 did not get assigned challenges using that device.

Once these hard criteria have narrowed the pool to challenges from the current mission whose device is available, a ranking algorithm assigns each candidate a value based on 3 other factors: skill progression, skill reinforcement, and variety.

1. *Skill progression:* If the new challenge is one skill higher than the last challenge the person completed, then it is given a high ranking. If it is more than one skill higher, it is given a low ranking. If it is the same skill or lower, it is given a neutral ranking. This factor creates a pull towards increasing the level of challenge.
2. *Skill Reinforcement:* The skill of the challenge compared to the current value of the skills in the individual's model. This factor looks at the skill used by the candidate challenge and compares it to the stored value for that skill and for the skill that is one level lower on the taxonomy in the individual's model. This factor makes sure that the challenge level does not increase too quickly, requiring the individual to have a certain number of "points" in the lower level skills before being assigned higher level skills.
3. *Variety:* Whether or not the individual just used that tangible. A slight preference is given for switching to a new tangible, to prevent boredom or the perception that one person is "hogging" a specific tangible. This factor mostly functions as a tie breaker between challenges that are evenly matched in terms of the previous two factors.

Each time a challenge is completed, the value for the skill associated with that challenge is updated in the user model. Three factors determine how the value is changed: whether or not they answered correctly, whether or not they got help in completing the challenge, and whether they rated it Easy, Just Right, or Hard.

3.2 Family Model

Compared to the calculations involved in the individual model, the group model of the family was quite simple. The primary thing the group model tracked was progress through each mission. Progress was calculated as a percentage out of 100. Each time a task was completed, or five minutes passed, the progress was incremented by a certain amount. When the progress reached over 60%, challenges stopped being assigned to individuals and the group was instructed to return to the table when all current challenges were completed. The group would thus typically return to the table with 60-80% of the mission completed. After reviewing the challenges completed during the first round, a second round would be assigned to bring the total up to 100% through the mission. The amount of progress that each challenge counted for was determined by the number of people in the group to keep smaller groups from having to do more tasks to finish a single round. Using both challenge completion and time passage to increment the progress counter helped prevent slower families from getting frustrated or feeling trapped within a single round.

4 User Studies

In our evaluation, families tested Kurio in a local history museum. The number of participants was 58 parents and children, or 18 families. The family sizes ranged from 2 to 4 people and in a few cases a family friend joined the group. In most cases, a single parent accompanied one or more children, but in one case two parents participated. There were 35 children between the ages of 7–12: 20 boys, 15 girls. There were 4 children between the ages of 13-17: 2 boys, 2 girls. And there were 19 parents (15 mothers, 4 fathers) ranging in age from 24 to 57.

The evaluation of the system was performed in two phases three months apart, using the same protocol. The second phase differed from the first one in that it had a more robust version of the system. We also made a few small adjustments to the design of the tangible devices, such as a recessed on/off switch and reducing the number of control buttons on the listener from three to two. We also updated the user modeling component in several ways. We adjusted the bootstrapping values and some parameters in the group user model, especially related to timing of the session to achieve about the same experience for families with different number of people.

The families were recruited from the local area by way of mailing lists and notices circulated at the local schools and homeschooling groups. 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. Two separate questionnaires were administered, one for children aged 7 to 12 and one for parents and children older than 13. The sessions were both videotaped and audio recorded. Lastly, 2-4 weeks after the study and on a volunteer basis, families conducted self-administered audio-recorded interviews based on a script we provided.

4.1 Questionnaire Data for 7-12 Year Olds

Table 1 shows the responses to Likert scale questions using smiley faces that were converted to a scale of 1-5, with 5 being best. The questionnaire was based on Read and MacFarlane's "Fun Toolkit" for children [16]. The questions assessed general perceptions of use, fit of the system with the family, and benefits with respect to learning and enjoyment. We first used a mixed model to test for within-family (intraclass) correlations in the responses, which would invalidate standard statistical analysis methods if present [17]. These were all found to be negligible. We then tested for the significance of the difference between the means of two phases using a 2-sample t-test. Cases with significant difference (5% level) between Phases 1 and 2 are indicated in Table 1.

Table 1. Questionnaire for 7-12 year olds. The values in the columns represent mean and standard deviation. The mean is from a 5-scale Likert scale converted from smiley faces, 5 being the best. *Mean difference between phases 1 and 2 is significant at 0.05 level (2-tailed).

Question	*Phases 1 (N=14)*	*Phase 2 (N=19)*	*Phases 1+2 (N=33)*
A. Did you have fun with Kurio?	3.64, 0.92	4.15, 0.89	3.93, 0.93
B. Was Kurio easy or hard to use?	3.42, 1.01	3.15, 0.50	3.27, 0.76
C. Were the challenges given by Kurio easy or hard?	3.28, 0.72	3.47, 0.77	3.39, 0.74
D. Were you excited or bored about the next challenge given to you by Kurio?	*3.07, 0.73	*3.84, 1.21	3.51, 1.09
E. Was Kurio helpful in learning about things in the museum?	*3.42, 0.64	*4.10, 0.80	3.81, 0.80
F. Was Kurio fun to use with your family?	*3.42, 0.85	*4.10, 0.93	3.81, 0.95
G. Is using Kurio a good way to visit a museum?	3.92, 0.64	4.15, 0.89	4.06, 0.80

4.2 Questionnaire Data for Ages 13+

The second questionnaire was given to parents and children 13 years old and older. The questionnaire included twenty-four Likert scale questions from 1-5, with 5 being best. The results are in Table 2. Again, we tested for the significance of the difference between the two phases using a 2-sample t-test, after finding intra-class correlations to be negligible. Cases with significant difference between Phases 1 and 2 are indicated in the last column.

Table 2. Questionnaire for ages 13+. The values in the second and third columns represent M, SD, and N. The mean is from 5-scale Likert scale converted from smiley faces, 5 being the best. *Mean difference between phases 1 and 2 is significant at 0.05 level (2-tailed).

Question	*Phase 1*	*Phase 2*	*Phases 1+2*
A.1 How much fun was Kurio?	*3.7, 0.94, 10	*4.58, 0.66, 12	4.18, 0.9, 22
A.2 How confident do you feel about using Kurio after the evaluation?	4.11, 1.16, 9	4.41, 0.66, 12	4.28, 0.9, 21
A.3 Did Kurio require a large effort to learn?	3.3, 1.41, 10	3.75, 0.86, 12	3.54, 1.14, 22
A.4 Did your attitude toward Kurio become more or less positive as the evaluation progressed?	4.1, 1.19, 10	4.66, 0.49, 12	4.4, 0.9, 22
B.1 How well did Kurio help you in exploring the museum in ways that interested you?	*3.6, 1.07, 10	*4.5, 0.67, 12	4.09, 0.97, 22
B.2 How well did Kurio let you enjoy the museum with your family and or friends?	3.77, 1.2, 9	4.5, 0.67, 12	4.19, 0.98, 21
B.3 How well did Kurio help you learn about the museum exhibition and the artefacts?	*3.6, 1.07, 10	*4.58, 0.66, 12	4.13, 0.99, 22

Table 2. (*continued*)

B.4 How well did Kurio let you learn together with your family and or friends about the museum exhibition and the artefacts?	*3.55, 1.5, 9	*4.66, 0.49, 12	4.19, 1.16, 21
C.1 How well does Kurio fit in with the exhibition environment?	3.8, 1.03, 10	4.5, 0.79, 12	4.18, 0.95, 22
C.2 How integral a part did Kurio feel with the exhibition?	3.4, 1.26, 10	4.08, 0.9, 12	3.77, 1.1, 22
C.3 Did using an interactive system like Kurio benefit your experience of the museum exhibition?	*4.11, 1.05, 9	*4.91, 0.28, 12	4.57, 0.81, 21
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?	4.2, 1.31, 10	4.91, 0.28, 12	4.59, 0.95, 22
C.5 If you were the monitor (used the PDA), how much do you feel you helped others in exploring the museum?	*4.12, 0.83, 8	*4.75, 0.45, 12	4.5, 0.68, 20
D.1 Is using Kurio a good way to visit the museum?	4.3, 0.94, 10	4.83, 0.38, 12	4.59, 0.73, 22
D.2 How easy was Kurio to use?	3.5, 1.17, 10	4.25, 0.45, 12	3.9, 0.92, 22
D.3 Were the challenges Kurio assigned helpful in exploring and learning in the museum?	*3.8, 0.78, 10	*4.5, 0.52, 12	4.18, 0.73, 22
D.4 How interested were you to get the next challenges assigned?	*4.11, 0.6, 9	*4.75, 0.45, 12	4.47, 0.6, 21
D.5 If you or a member of the family completed a challenge successfully, how difficult was the next one?	*3.62, 1.4, 8	*4.72, 0.46, 11	4.26, 1.09, 19
D.6 If you or a member of the family did not complete a challenge successfully, how difficult was the next one?	*4.0, 0.89, 6	*4.87, 0.35, 8	4.5, 0.75, 14
E.1 How much did you discover that you did not know previously?	3.8, 0.78, 10	3.91, 0.66, 12	3.86, 0.71, 22
E.2 How much more did you learn about things you already knew?	3.5, 1.06, 8	3.83, 0.83, 12	3.7, 0.92, 20
E.3 How much more curious did the museum experience make you?	4, 0.81, 10	4.33, 0.65, 12	4.18, 0.73, 22
E.4 How exciting was it to learn?	*3.8, 0.78, 10	*4.58, 0.51, 12	4.22, 0.75, 22
E.5 Some of what I learned will be useful to me?	2.88, 1.36, 9	4.16, 0.71, 12	3.61, 1.2, 21

4.3 Experience Structuring Factors

In addition to the interview and questionnaire data, we also saved the system log data for every study session. The log captured the fine grained interaction activities of each individual and family, including the challenge assignments, selection and de-selection of objects, activity at the tabletop, and responses to the post-challenge feedback

Table 3. Experience structuring factors extracted from log data

Factor	*Description*
Number of Challenges	Number of successfully completed challenges
Number of Quits	Number of challenges the user quit. As this was the way to overcome some technical glitches, its semantics represents failures of the system.
Being helped	Number of challenges where user responded that s/he received help.
Relative Time Helping Others	A ratio of time without an assigned challenge when user was asked to help other family members to time spent on solving their own challenge.
Average of Difficulty	Five last challenges were used with the latest challenge weight set at 5 and weight going backwards to 1.
Deviation From Just Right	Ratio between challenges rated Easy and Hard and total number of challenges.
Difficulty Sequential Change	Average change in difficulty between subsequent tasks measured in absolute values (e.g. change from Hard to Easy is 2)

questions. To better understand the individual interaction sessions we have extracted interaction characteristics we call experience structuring factors from the log data (see Table 3 for their description).

The last three factors in Table 3 are derived from the patterns of the difficulty ratings as ranked by the user after completion of the challenge. The users were asked to rank difficulty as "Easy", "Just Right", or "Hard". To compute the factors that represent the difficulty of a varying sequence of challenges we have assigned them values of 0, 1, and 2 respectively. In the following section we explore which factors have the highest influence on the user learning in the museum.

4.4 Assessing Importance of Experience Structuring Factors

We wish to identify experience structuring factors that have strong associations with each of the questionnaire response variables. In this context, bivariate correlations between response and explanatory variables are of limited utility, as they do not adequately account for multicollinearity (hidden multivariable correlations) among the explanatory factors [18]. Also, model-selection procedures such as stepwise selection are inappropriate on several levels: they select a single combination of variables that may not be best by any objective measure and they ignore the effects of random variability on the model selection process [19]. We do not seek to use a model for predicting responses. Instead, we use a variable-selection approach that considers all explanatory factors simultaneously and assesses their relative importance in explaining variability in the response variables.

Method. For each response variable we fit models consisting of all possible combinations of explanatory variables, including the empty model, and calculated a model-assessment criterion, the corrected Akaike Information Criterion (AICc), on each model. We converted the AICc values to model weights so that the relative sizes of the weights reflect the relative fit of the model: good-fitting models have large weights and poor-fitting models would have weights close to zero. The weights were normalized to sum to 1 over the set of all models. Then we calculated factor weights for each explanatory factor by summing the weights corresponding to all models in which the factor appears. In this manner, factors that are consistently a part of the best-fitting models have weights close to 1, while those that are not generally included in good-fitting models have factor weights near zero. Details on this factor weighting procedure can be found in [19]. Finally, we applied a strict threshold (0.95 out of 1 for '++' or '--' ranking and 0.90 of 1 for '+' rank or '-', with the sign determined by the sign of the corresponding regression coefficients) to consider the factor as important to explain the variability in the questions and worth paying attention to in further research and design of systems like Kurio.

Model for ages 8-12. Factors found as important using the method above are listed in Table 4. For other questions from the questionnaire for 8-12 year olds (Table 1), no other variables came out as sufficiently important. In those cases, the mean and standard deviation as listed in Table 1 provide the best guidance for future research.

Table 4. Experience Structuring Factors Model for ages 8-12

Question	*Factors*
E. Was Kurio helpful in learning about things in the museum?	Number of challenges completed (--)
F. Was Kurio fun to use with your family?	Difference from just right (--), Relative time to help others (--)

The first finding is very surprising. It indicates that with increasing number of challenges completed, we can expect children to judge the Kurio's ability to help them learn about things in museum less. To put this into perspective, the average number of challenges completed in this age group was 4.22 (SD=2.16, N=31) with maximum number of challenges being 10 and minimum 1. This is a strong indicator that although they had fun with the system and considered Kurio to be a good way to visit museum (Table 1), the actual learning can be hindered by excessive number of challenges. *As a guideline, the pace of interaction has to be carefully tested before any serious deployment of the system.*

The second finding indicates that the two factors negatively influence the fun factor in the context of the family visit. First, difference from just right is a good confirmation that *if system assigns challenges at the right level, this increases the value of the visit as a family.*

The relative time to help others factor is a relative measure of the time without challenges against time spent solving their challenge in each mission. As rounds of challenges were wrapped up, individuals who completed their individual assignments were not given new ones and were instead asked to help the others in their family. Depending on how quickly they did their challenge and how long their family members took, they could spend a significant amount of time without anything specific to do.

The interpretation of the finding is fairly straightforward; *when individuals have nothing to do, they become bored and start to feel negatively about the experience, or helping others learn is less valued than learning themselves.*

Although a high amount of time helping others may have caused boredom for some users, others commented explicitly in the interviews that they enjoyed working together to complete the missions. In one of the self-administered interviews completed a couple weeks after the Kurio interaction, one family had the following exchange in response to the question "What did you like best about Kurio?"

Jenna: *I liked trying to help other people do it. I don't know why.*
Sharon: *I know, that's a good reminder, I liked that too, working together…*
Jenna: *Not just, oh it's all about me, I can only do it.*
Sharon: *Yeah, the problem solving was kind of fun, I liked figuring it out together.*

No one in the interviews complained that the Kurio system isolated them from their family members or inhibited social interaction, so in that regard at least the system was successful in correcting issues observed in individually focused systems.

Model for ages 13+. Factors found as important for age group 13+ are listed in Table 5. The users had an option to quit a challenge and be assigned a new one when they found the challenge to be too difficult or uninteresting. Unfortunately, we used the quit mechanism also as a way to fix technical glitches with tangibles. This became the predominant use of this capability. The higher number of quits due to technical problems rather than difficulty influenced the variability in answers to several questions. The second uncontrollable factor that influenced some questions strongly was age (mean of 38.9, SD=12.6, N=19).

Table 5. Experience Structuring Factors Model for 13+ year old

Question	*Factors*
A.4 Did your attitude toward Kurio become more or less positive as the evaluation progressed?	Age (++), Number of challenges completed (++), Being helped (--), Relative time to help others (--)
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?	Number of challenges completed (--)
C.5 If you were the monitor (used the PDA), how much do you feel you helped others in exploring the museum?	Number of quit challenges(-)
D.2 How easy was Kurio to use?	Number of quit challenges (-)
D.4 How interested were you to get the next challenge assigned?	Number of quit challenges (-)
D.5 If you or a member of the family completed a challenge successfully, how difficult was the next one?	Age(--), Number of quit challenges (-)
D.6 If you or a member of the family did not complete a challenge successfully, how difficult was the next one?	Number of quit challenges (-)
E.5 Some of what I learned will be useful to me?	Number of quit challenges (-) Relative time to help others (--)

The attitude towards Kurio is higher with number of challenges completed, which is an expected result. However, the positive view is negatively affected relative to the time spent to help others, i.e. the more time spent with others. The previous explanation presented in the paragraph above seems to apply in this case as well. Another aspect that negatively affects positive attitude toward the system is being helped, meaning that adults do not like it when they are being helped. This aspect is interesting and we plan to further investigate this issue.

There is also a significant finding with respect to learning in the question E.5 that reflects the similar finding in the model for the age group 8-12.

5 Conclusions

We presented a system, Kurio, which supports family visits in museums with a mixture of technology including specialized tangible devices, a personal digital assistant, and a tabletop computer. The families engage in an educational game where family members are assigned individual challenges and their progress is monitored by coordinated by the family member with PDA. After each round of challenges, the family returns to the tabletop computer to review their progress, obtain rewards, and is guided to the next round of challenges.

We have evaluated the Kurio with 18 families (54 participants) in a local museum. In addition to the session using Kurio that lasted on average 45 minutes, the participants filled in pre and post-test questionnaires, provided post-session structured interviews, and also self-administered audio interviews 2-4 weeks after the session. The evaluation was organized in two phases.

In this paper we reported the questionnaire results for age groups 8-12 and 13+. The evaluation of the Kurio overall was very positive. We also extracted several factors from the log data. We applied a model discovery method to determine which factors play important roles in determining users' perception about the Kurio system and support learning in the museum.

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