ec(h)o: Situated Play in a Tangible and Audio Museum Guide

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ABSTRACT

In this paper we discuss an adaptive museum guide prototype in which playfulness is a key design goal for the interaction experience. The interface for our prototype is a combined tangible user interface and audio display. We discuss how we determined the specific requirements for play through an ethnographic study and analysis based on ecological concepts of Bell and Nardi & O'Day. We found that we could consider play in two main forms in regard to the interface: content and physical play. We also found that play is highly contextual. Designers need to consider the situated nature of play for two reasons: 1) to best serve the overall design purpose; 2) in order to understand the nature and degree of play required. We augmented traditional user experience evaluation methods of questionnaires and interviews with observational analysis based on Djajadiningrat's descriptions of aesthetic interaction.

Author Keywords

Tangible User Interface, Ludic design, adaptive museum guide, audio display, ethnography, information ecology

ACM Classification Keywords

Augmented Reality and Tangible U,I, Interaction Design

INTRODUCTION

In our adult lives play is an experience set apart from our everyday activities: Huizinga referred to play as invoking a *magic circle*, a liminal space for games [16]. Do we play in museums? Anthropologist Genevieve Bell identifies the notion of play together with learning in museums [2]. She describes museums as different *cultural ecologies* in which the museum visit has the qualities of *liminality* (a space and time set apart from everyday life) and *engagement* (where visitors interact to both learn and play).

Guided by the notion of play in a museum experience we considered playfulness as a primary design goal in the design of the interface for an adaptive museum guide. However, since *play* is a very rich and open-ended concept, a large part of our research was aimed at first determining and later evaluating the specifications for play in regard to an adaptive museum guide. In this regard, we are discussing a passive sense of play where enjoyment is a key element but it is not a goal in itself, as one would describe playing a game or a child playing with a toy.

We found that play is highly situated. It is important that the playfulness is not perceived to be separate from the museum environment to the point that it is distracting or does not make sense. With respect to our interface, we found that play can take two forms: (1) *content play* such as puns and riddles in informational content; (2) *physical play* that in our case consisted of holding, touching and moving through a space. The content play was dependent on surrounding informational cues or referents. The physical play was a simple playful action along the lines of toying with a wooden cube where play is open, subtle and implicit. In both cases, play creates a higher degree of engagement with the museum artifacts.

Our case study known as *ec(h)o*, includes a tangible user interface (TUI), spatial audio, and an integrated user modeling technique combined with semantic technologies. The focus of this paper is on the user interaction experience, for a discussion of our user modeling approach see [14]. We discuss related research to our case study followed by a discussion of our design motivations. We describe the ethnographic study, which led to our requirements for play. We provide an overview of the prototype that was installed and tested at Canadian Museum of Nature in Ottawa. We conclude with an analysis of our evaluation and a discussion of lessons learned.

RELEVANT RESEARCH

We aim in our prototype system, ec(h)o[1] to maintain a standard level of functionality with the exception of media rich delivery. We sacrificed the ability to deliver diverse types of media in order to gain the opportunity to move

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[1] The name ec(h)o comes from the audio experience of the work and the underlying idea of a museum as an ecology.

away from a graphical user interface (GUI) and the personal digital assistant (PDA) in the hopes of creating a more playful interaction through a physical and embodied interface. We also focused on the potential of audio to create imaginative and ludic possibilities.

Previous work most relevant to our case study includes museum guide systems that utilize an adaptive approach, GUI and PDA interfaces in museum guides, and a discussion of work outside of the museum domain that utilizes audio interfaces in ubiquitous and mobile computing contexts. Equally important to our discussion are the *ludic* qualities of tangible user interfaces, and related ideas of aesthetics and play in interaction.

Adaptive museum guide systems and audio display

Adaptation and personalization approaches have been successfully applied to museums in the context of the World Wide Web [6, 25] and in handheld museum guides. ec(h)o shares many adaptive characteristics with the handheld systems of HyperAudio, HIPS and Hippie [3, 24, 27]. Similar to ec(h)o, the systems respond to user's location and explicit user actions through the interface. All systems adapt content to the user model, location and interaction history. Among the differences relevant to this paper is that these systems depend on a PDA graphical user interface, ec(h)o uses audio display as the only delivery channel and a tangible object as an input device, ec(h)o treats user interests as dynamic, we look to evolving interests as a measure of sustainable interaction [14].

In museum guide systems there has been a strong trajectory of use of the PDA graphical user interface. Typically, hypertext is combined with images, video and audio [1, 30]. Yet, a PDA is essentially a productivity tool for business, not a device that lends itself easily to playful interaction. Nevertheless, museum systems are typically PDA-based despite shifts in other domains to approaches that better address the experience design issues most prominent in social, cultural and leisure activities [20]. The play constraints of these devices are too great for the level of interaction that goes beyond playing a software game on a mobile device. For example, in the area of games and ubiquitous computing, Björk and his colleagues have identified the need to develop past end-user devices such as mobile phones, personal digital assistants and game consoles [4]. They argue that we need to better understand how "computational services" augment games situated in real environments. The same can be said for museum visits.

Non-visual interfaces, particularly audio display interfaces have been shown to be effective in improving interaction and integration within existing physical contexts. For example, Brewster and Pirhonen [7, 29] have explored the combination of gesture and audio display that allows for complicated interaction with mobile devices. The *Audio Aura* project [21] explores how to better connect human activity in the physical world with virtual information through use of audio display. Audio is seen as an immersive display that can enrich the physical world and human activity while remaining integrated with the surrounding environment. In addition, audio tends to create interpretive space or *room for imagination* as many have claimed radio affords over television. In the HIPS project, different voices and delivery styles were used to create an "empathetic effect" between the user and the artifacts they engaged [20]. We've adopted a similar approach to our use of audio content.

The play of tangible user interfaces

Tangible user interfaces have a strong potential to be playful, imaginative and poetic user interfaces. Ishii's and Ullmer's notion of *coupling bits and atoms* was informed by earlier work in graspable interfaces [11] and real-world interface props [15]. ec(h)o's tangible user interface draws on this notion by coupling an everyday and graspable object, a wooden cube with digital navigation and information. Ishii was inspired by the aesthetics and rich affordances of scientific instruments [17] and the transparency of a well-worn ping-pong paddle [18]. Simple physical display devices and wooden puzzles at the natural history museum where we conducted ethnography sessions inspired us as well.

In 1992, Bishop's Marble Answering Machine [8] was an early embodiment of the immediate and playful qualities of tangible user interfaces. The prototype uses marbles to represent messages on the machine. A person replays the message by picking up the marble and placing it in an indentation in the machine. Jerimijenko's Live Wire is a strikingly minimal and whimsically simple demonstration of digital bits transformed into physical atoms [33]. Jeremijenko dangled a plastic wire from a motor attached to the ceiling. The motor accelerates or decelerates based on traffic across the Ethernet network. Ishii's PingPongPlus [18] explores the intertwining of athletic play with imaginative play. The ping-pong table becomes an interactive surface, the ball movement is tracked and projections on the table of water ripples, moving spots, and schools of fish react to where the ball hits the table.

Aesthetics of interaction

Researchers in human-computer interaction (HCI) have recently explored enjoyment [5] and ludic design [13] in interface approaches. Nowhere is this need more evident than in the richly interpretive and social environments of museums [12, 20]. Our emphasis is on the qualities of interaction that result in play that facilitates discovery. While we address this on an informational level in regard to our use of audio content and information retrieval [14], we found we equally explored the embodied and situated aspects of interaction or aesthetic interaction as expressed by Djajadiningrat [10] and Petersen [26].

Djajadiningrat argues for a "perceptual-motor-centered" approach to tangible interfaces [10]. He argues for a "direct approach" for its "sensory richness and action-potential" of the objects to carry meaning through interaction. He describes this notion of meaning in interaction as *aesthetics of interaction* whereby the "beauty of interaction" as opposed to the beauty of the artifact or interface, tempts the user to engage as well as "persevere" in their engagement [10].

Petersen and her colleagues' description of aesthetic interaction shares the embodied aspects described above as well as the sense of aesthetic potential that is realized through the action or engagement [26]. For example, Petersen developed a playful interaction approach as part of the WorkSPACE project utilizing a ball that is thrown against a floor projection of documents and work materials as a way of manipulating and exploring the information. Inherent to the ball are kinesthetic challenges, affordances and the situated relationship with the environment. These aspects are realized in action with the object including the playful actions of aiming, throwing and bouncing.

DESIGN MOTIVATIONS

Historically, links have been established between play and learning. For example Dewey argued for the *construction* of knowledge based on learning dependant on action [9]. Piaget, through his child development theory described the development of cognitive structures through action and spontaneous play [28]. More recently, Malone and Lepper consider games as intrinsic motivators for learning [19]. In the museum context, Bell's *cultural ecologies* [2] ascribe the museum visit with qualities of *liminality* (a space and time set apart from everyday life) and *engagement* (where visitors interact to both learn and play). Yet for designers, the specific requirements and attributes of play described above are elusive and too general. We utilized design ethnography informed by Bell's *cultural ecologies* [2] and Nardi's and O'Day's *information ecology* [23] as a means of defining play for the design of our prototype.

This approach led to us to be inspired by simple physical displays, puzzles, and connections between key people and the artifacts that we observed in our ethnographic sessions. Key observations included:

- Highly tactile and hands-on approaches to artifacts and displays including holding, and manipulating;
- Visitors are not spoon-fed factual information in the form of didactics, rather they engage in play and learning through puzzles, games and physical displays;
- Lively storytelling of the museum staff and researchers about the museum collection was often humorous as well as informative.

Our team spent over seventy hours conducting interviews, video walkthroughs, and site visits with over thirty researchers, staff, and administrative staff at the museum. We also observed exhibitions and museum visitors and conducted an analysis of interaction devices in the museum.

Museums as ecologies

Bell sees the museum visit as a ritual determined by space, people and design [2]. She decomposes the visiting ritual into three observational categories: space, visitors, and interactions and rituals. Different types of museums have different ecologies, for example Bell describes different attributes between art and science museums. These ecologies are seen to be distinct and supportive of very different kinds of museum visits. Bell also describes interaction concepts that are common to all museum ecologies. We have drawn on two of these concepts in developing our approach, *liminality* and *engagement*:

- *Liminality* defines museums as places that embody an experience apart from everyday life. Positive museum experiences are transformative, spiritual, and even moving. A museum visitor should be inclined to pause and reflect, thus liminality can be seen to permit a deeper engagement.
- *Engagement* is a key concept for museums as people go to museums to learn, however this engagement is often packaged in an entertaining way; museums are a balance between learning and entertainment spaces.

Nardi and O'Day draw on activity theory [22, 31] and field studies to develop their concept of *information ecologies*. The concept they describe strives for a systematic view of organizations based on the relationships among people, practices, technology, values and locale. For example, a library is an ecology for accessing information. It is a space with books, magazines, tapes, films, computers, databases and librarians *organically* organized to find information. Nardi and O'Day utilize the concept of ecology in order to depict the complex relationship among elements and influences of which technology is only one part. Constituent elements of information ecologies include a *system*, *diversity*, *co-evolution*, *locality*, and *keystone species*. Two of these elements were essential in supporting our design:

Locality can be described as participants within the ecology giving identity and a place for things. For example, the *habitation* of technology provides us with a set of relationships within the ecology, to whom a machine belongs determines the family of relationships connected to the technology. In addition, we all have special knowledge about our own local ecologies that is inaccessible to anyone outside thus giving us local influence on change.

Keystone species are present in healthy ecologies; their presence is critical to the survival of the ecology itself. Often such species take the role of mediators who bridge institutional boundaries and translate across disciplines.

Design implications of our design ethnography

Our observations that fall within Bell's categorization of *interaction and ritual* emphasized that our system should be open to multiple forms of input such as movement and

Figure 1 A wooden puzzle interactive (left) and a "discovery drawer" (right) found in the "Finders Keepers" exhibition

physical interaction with the displays, and responsive to different learning styles.

The displays and installations revealed diverse forms of interaction: microscopes with adjustable slide wheels that could be turned to explore different specimens; wooden puzzles which, once completed, would fall apart at the pull of a handle, creating a loud crashing sound that captured the attention of others (Figure 1); a collecting game called *The Rat Pack Challenge* which tasked visitors to search the room and discern collectable artifacts from non-collectable ones; discovery drawers filled with objects like fossils, fur pelts, and minerals which visitors could touch and inspect at close range (Figure 1); magazines, coloring books, and a small library of natural history artifacts that were lent to students.

Bell notes that an attribute of science museum ecologies is to support the fact that people learn in a variety of ways. Alternative approaches to learning turned up throughout our observations, such as the interactive puzzles, quizzes, and games that require visitors to explore and think about the artifacts on display.

Design implications: the observed activities support a highly tactile approach that includes holding, manipulating and being highly interactive with your hands. A tangible user interface would situate itself well among these puzzles, games and physical displays. Another design implication is the use of puzzles and riddles as modes of interaction and content delivery. Visitors are not spoon-fed factual information in the form of didactics, rather they engage in play and discovery to learn about the artifacts and the broader concepts that tie the artifacts together thematically.

Stories and information we heard in our interactions with museum staff and researchers were examples of the ecology concepts, *locality* and *keystone species* as defined in Nardi's and O'Day's *information ecology*. We observed numerous informal yet engaging stories that communicated the specialized knowledge of the researchers. These were first hand accounts and discussed in a wide-ranging manner. Factual or thesis driven accounts of artifacts were mixed with anecdotal and humorous tales related to the discovery, processing or research of the actual artifact. This experience deeply struck us since our shared perception of the public exhibition display space was quite the opposite. Not unlike many exhibitions, the artifacts and contextualizing information appeared static and lifeless, the puzzles and games notwithstanding. In *locality* terms, it was evident to us that once the artifacts were connected to people, the understanding of these artifacts became deeply connected to all aspects of the ecology and came out in the form of storytelling that covered activities related to the artifact, conservation, storage, research and display technologies, meaning and values associated with the artifacts.

Design implications: As a result we felt the need to bring this degree of liveliness to the artifacts on display. We modeled our content delivery and audio experience on the informal and humorous storytelling we had experienced, extending it through riddles and word play. We aimed to create a virtual cocktail party of natural history scientists that accompanied the visitor through the museum.

PROTOTYPE

In order to better understand the prototype we tested, we provide a typical visitor scenario and describe the system. The prototype is composed of a tangible user interface, spatial audio display and an integrated user modeling technique combined with semantic technologies. While arguably other interface approaches could have been utilized, such as a simple push-button device for input or a mobile text display device for output, such a strategy would be incongruent with our experience design goals.

Visitor scenario

The scenario refers to an exhibition about the history and practice of collecting natural history artifacts:

Visitors ec(h)o selected topics related to the exhibition to establish their interests for the system. An attendant gives the visitor a wooden cube that has three colored sides, a rounded bottom for resting on her palm and a wrist leash so the cube can hang from her wrist, and headphones connected to a small, light pouch to be slung over her shoulder. The pouch contains a wireless receiver for audio and a digital tag for position tracking.

Our visitor moves through the exhibition space. Her movement creates her own dynamic soundscape of ambient sounds. She passes a collection of animal bones and hears sounds that suggest the animal's habitat. The immersive ambient sounds provide an audio context for the collection of objects nearby.

As she comes closer to a display exhibiting several artifacts from an archaeological site of the Siglit people, the soundscape fades quietly and the visitor is presented with three audio prefaces in sequence. The first is heard on her left side in a female voice that is jokingly chastising: "Don't chew on that bone!" This is followed by a brief pause and then a second preface is heard to her center in a young male voice that excitedly exclaims: "Talk about a varied diet!" Lastly, a third preface is heard on her right side in a matter-of-fact young female voice: "First *dump…then organize." The audio prefaces are like teasers that correspond to audio objects of greater informational depth.*

The visitor chooses the audio preface she heard on her left side in order to learn more about it, by holding up the wooden cube and rotating it to the left. This gesture selects and activates an audio object. She hears a chime confirming the selection. The audio object delivered in the same female voice as the related preface yet in a relaxed tone. It describes the degree of tool making on the part of the Siglit people: "Artifact #13 speaks to the active tool making. Here you can actually see the marks from the knives where the bone has been cut. Other indicators include chew marks…"

After listening to the audio object, the visitor is presented with a new and related audio preface to her left side, and the same prefaces that she did not choose earlier, are heard again to her center and right side. The audio prefaces and objects presented are selected by the system based on the visitor's movements in the exhibition space, previous audio objects selected, and her current topic preferences.

Tangible user interface

The tangible user interface is a shaped wooden cube with three adjacent colored sides (Figure 2). The visitor makes a selection by holding the cube in front of them and rotating it. The cube was carefully designed to ensure proper orientation. The "bottom" of the cube has a convex curve to fit comfortably in the palm of the visitor's hand and a wrist leash is attached to an adjacent side to the curved bottom suggesting the default position of being upright in the palm and at a specified orientation to the visitor's body. The leash allows visitors to dangle the cube when not in use and frees the use of their hand. The opposite side of the bottom of the cube is colored and when this side is held up the audio preface to the visitor's center is selected (additional support is provided by an icon denoting a pair of headphones with both channels active printed on this side). If the visitor rotates the cube to the left or right, the audio prefaces on each side are selected. The sides to the left and right are each uniquely colored and display icons showing active left and right channels of the headphones, respectively. The cube is made of balsa wood and is therefore very light (approximately 100 grams or 3.5 ounces), less than a typical networked PDA.

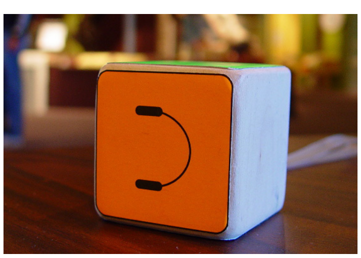

Figure 2. The ec(h)o cube

The ergonomic design of the cube and biomechanics of arm and wrist movement form a physical constraint that ensures that the selected cube face is almost always held parallel to the camera lens above and so highly readable. We experienced no difficulties with this approach.

Technically, the input of the selection is done through video sensing. We used the "eyes" vision system (http://www.squishedeyeballs.com), which included an array of color video cameras connected to a desktop computer in order to cover specified interactive zones. Each interactive zone included a single camera positioned on the ceiling above in order to detect the rotation of the cube by visitors.

Audio display

For the *prefaces* and *audio objects* we used a simple spatial audio structure in order to cognitively differentiate between the options heard. Switching between the stereo channels created localization: we used the left channel audio for the left, right channel audio for the right, and both channels for the center. It is an *egocentric* [9] spatial structure that allowed the three *prefaces* to be distinguishable and an underlying content categorization structure to exist. The spatialization was mapped to the tangible interface for selection. In addition, we provided simple chimes to confirm that a selection had been made.

The *prefaces* were written to create a sense of surprise, discovery and above all play, especially in contrast to the informational audio objects. In order to create this sense we utilized diverse forms of puns, riddles and word play, for example:

Ambiguous word play: "Sea urchins for sand dollars" (preface); "Other then the morphology, the sea urchin and the sand dollar are very similar species…" (abridged audio object);

Simple pun: "Its like putting your foot in your mouth" (preface); "The word gastropod comes from two different roots: *gastro* for stomach, and *pod* for foot" (audio object);

Literary pun: "Dung beetles play ball!" (preface); "Dung beetles turn dung into balls and are equipped with their forehead and legs to push these balls for some distance…" (abridged audio object);

Turn of phrase: "An inch or two give or take a foot" (preface); "Dung beetle nests are usually underground, and can range from a few inches to a few feet deep" (audio object);

Definition pun: "There's a cat in the garden!" (preface); "Specimen #129 is a John Macoun sample, it is known as a pussy toe because the plant flower and fruit represent a cat's foot" (audio object);

Riddles: "What is always naked and thinks on its feet?" (preface); "Where gastropods are shelled critters with stomachs that sit on a primary foot, cephalopods are bare critters with heads that sit on a primary foot" (audio object);

Understatement: "Longer than you'd want to know" (preface); "Tapeworms come in varying lengths and sizes. Interestingly, the longest recorded tapeworms have been those that live in humans" (audio object);

Implausibility: "Ice age dentistry" (preface); "This deformed tooth is a very interesting case. It was the first recognized pathological problem in an ice age animal" (audio object).

The audio recordings of the *prefaces* and *audio objects* used a diverse set of voices that were playful in tonality and style. This added to the conversational feel and created an imaginary scene of a virtual cocktail party of natural historians and scientists that followed you through the museum. As we discussed above, we identified natural history scientists as our *keystone species*. We organized sessions of recorded walkthroughs of the exhibition asking each scientist to provide commentary [32]. These sessions became the basis for the discrete audio objects that were categorized by topics and relationship to artifacts on display.

An additional component to the audio display is the soundscape, which is discussed in the following section on navigation. For the technical implementation of the audio display we developed a multi-channel editor, mixer and server in the Max/MSP™ environment that functioned as an audio engine. This engine created dynamic soundscapes and delivered unique channels of stereo audio to individual users over FM transmitters. Each visitor carried a small inexpensive digital receiver in a pouch. We produced over 600 reusable and annotated audio objects. The average length of an audio object is approximately 15 seconds. The shortest is 5 seconds and the longest 31 seconds. The prefaces typically are 3 seconds in duration.

Navigation

We structured navigation at a *macro* level, where visitors move throughout the exhibition space in between artifact displays, and a *micro* level, where visitors are within a specified interactive zone in close proximity to an artifacts display.

On the macro level the input is the visitor's movement, which is tracked using a combined Radio Frequency Identification (RFID) and optical position tracking system developed by Precision Systems (http://www.precision-sys.com). The movement triggers an ambient soundscape that is made of sounds related to artifacts near the visitor (figure 3). We divided the exhibition space into interactive zones and mapped concepts of interest to each zone and display. The concepts are translated into environmental sounds such as the sound of an animal habitat, and sound of animals such as the flapping of crane's wings. The visitor navigates the exhibit exploring it on a thematic level through the ambient sounds that are dynamically created. If

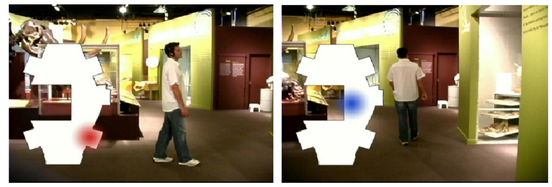

Figure 3. Ambient soundscapes related to artifacts in proximity of the visitor as they move through the exhibition. The highlighted areas on the map depict display related audio being played at the time. The red highlight (left image) signifies artifacts related to the visitor's interests.

a set of concepts strongly matches the visitor's interest the related audio is acoustically more prominent.

On the micro level, when visitors are within a meter or more of an artifacts display. The navigation is as follows: as previously discussed, a visitor is played three *prefaces,* one to his left, another to his center and the third to his right (figure 4). He selects the *preface* on his right side by rotating the tangible object, and listens to the linked audio object. On the subsequent turn the visitor hears the same two *prefaces* he did not select, and again he hears them to his left and to his center. Since he previously chose the *preface* to his right he now hears a new *preface* in that location. If the visitor then selects the center *preface,* on the subsequent turn only that *preface* is replaced by a new *preface* in the center position. If a *preface* has been replayed three times without being selected, it is replaced by a *preface* and audio object of the next highest-ranking topic according to the user model.

User model

For an in depth discussion and evaluation (not included in this paper) of the adaptive user model approach in ec(h)o we refer readers to [14]. Our approach can be summarized as the use of a modeling technique supported by ontologies and rules for information retrieval.

EVALUATION

We installed the ec(h)o system in an existing exhibition about collecting called 'Finders and Keepers' at the Canadian Museum of Nature. We created three interactive zones and a complete soundscape.

We performed two sessions of evaluation, a short session and an in-depth session. We evaluated user experience through observation and video analysis. We added questionnaires and semi-structured interviews for the in-depth sessions.

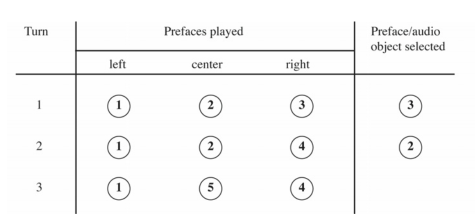

Figure 4. Illustration of micro level navigation

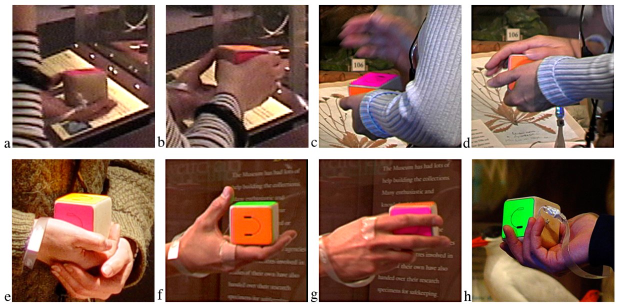

Figure 5 Different techniques for selecting prefaces: (a-b) Hold and rotate; (c-d) Hold, rotate and cover; (e) Cradle and hide; (f-g) Rotate wrist; (h) Rotate with fingers

The short session evaluation included thirteen participants drawn from the public. The participant group included five men and eight women, ranging in age from 25 to 54 years old. Participants were given brief introductions to the system, used the system, and completed a brief questionnaire. Each session lasted 12-15 minutes on average.

The in-depth user evaluation effort involved sessions with six participants drawn from the public. The participants had previous experience with interactive museum systems such as docent tours (3 participants), interactive kiosks (3), audiotape systems (4), film and video (5), seated and ride-based systems (2) and personal digital assistant systems (2). The tested group included two men and four women, from 25 to 53 years old. The participant sessions lasted 45-60 minutes on average. In addition, two expert reviewers tested the system. The experts included a senior researcher and senior interaction designer from the museum. Both were familiar with the exhibit and its underlying concepts. In addition to an extended discussion with the expert reviewers they provided us a written evaluation of the system.

Evaluation of aesthetic interaction

Earlier we discussed examples of the types of word play, puns and riddles we used in our audio display and content delivery in order to encourage play and discovery. The tangible interface aimed for a complementary physical play, which can be subtle and implicit like toying with a ball in your hand. We designed the tangible object such that it had suggested actions like resting in a palm or pivoting on a wrist yet we knew we could not design the actions directly rather only suggest possibilities, what Djajadiningrat refers to as the *action-potential* of physical objects [13]. Djajadiningrat describes three factors as having a role in aesthetic interaction: the *interaction pattern* of timing, rhythm, and flow between the user and the object; the *richness of motor actions* found in the potential space of actions and skill development; and *freedom of interaction* in which a myriad of interaction paths coexist.

The physicality of objects interacts with our bodies in unique and varying kinesthetic combinations in which optimal efficiency gives way to play and experimentation. In simple actions of holding and rotating the cube, we observed a diverse set of interaction techniques when selecting *prefaces*. We identified at least five basic types all of which successfully operated the system:

- *Hold and rotate*, one hand holds the cube resting on the palm while the other hand rotates it in place (see Figure 3(a-b));
- *Hold, rotate and cover*, one hand holds the cube resting on the palm while the other hand or both hands rotate the cube. The topside is uncovered until the selection is made and then the topside is covered again until its time to make another selection (see Figure 3(c-d));
- *Cradle and hide*, two hands rotate and cradle the cube, after selection is made the colored side is rotated and hidden against the visitor's body (see Figure 1(e));
- *Rotate wrist,* one hand holds the cube between fingers and thumb, and rotates the wrists to make a selection (see Figure 3(f-g));
- *Rotate with fingers*, one hand holds the cube and rotates it by rolling with the fingers and thumb (see Figure 3(h)).

It is important to note that we observed combinations and variations of these techniques, as well as individual experimentation with the different approaches. As one might expect, we also observed a range of methods for holding the cube when not selecting prefaces or walking through the exhibition such as cradling it in hands, holding it at one's side or behind one's back, dangling it from the wrist, or holding its leash to gently sway it from side to side.

This sense of play extended to participant's movements through the exhibition space. In the interviews participants commented on how they returned to zones to see if the system would indeed not repeat audio objects already heard. We observed participants moving from zone to zone straddling the boundaries of the interactive zones and soundscapes appearing to experiment with their movements and the soundscapes created by entering and exiting zones.

Evaluation of user experience

Our formal evaluation of user experience took place in the in-depth session. In addition to observation, we added a questionnaire, and a semi-structured interview. The questionnaire included sixty-three questions that assessed user experience related to the overall reaction to the system, the user interface, learning how to use the system, perceptions of the system's performance, the experience of the content, and degree of navigation and control. Majority of the questions in the questionnaire were on a Likert scale yet it provided for open-ended written comments. For a summary of the questionnaire results see Table 1.

Overall, participants found the system enjoyable and stimulating, perhaps in part due to its novelty. The general sense of satisfaction was split between those participants

Categories	Avg	SD
Overall reaction (5 questions including "terrible-wonderful; difficult-easy".	3.60	0.78
Tangible user interface (7 questions including "uncomfortable-comfortable; difficult-easy to manipulate; annoying-enjoyable"	4.24	0.50
Headset (2 questions including "comfortable-uncomfortable to wear"	2.92	0.12
Learning curve for the system (8 questions including "difficult-easy to get started; risky-safe to explore features; unclear-clear feedback)	4.07	0.36
Perception of system performance (8 questions including "slow-fast system response; never-always reliable"	3.83	0.39
Quality of the content (15 questions including: "uninformative-informative; generalized-customized for me; rigid-playful; predictable-surprising"	3.78	0.52
Quality of the audio experience (9 questions including "confusing-clear; mechanical-human-like; wasteful-valuable"	3.67	0.30
Navigation and control (8 questions including "never-always able to navigate in an efficient way; always-never found myself lost in the system; always-never found myself uncertain of system state	3.23	0.29

Table 1 Summary of the questionnaire results (n=6; 63 questions on Likert scale of 1-5 (5 being best)

who liked the playful approach and those who did not. We noted a clear age difference in that the "younger" participants rated satisfaction higher based on their liking of the playful approach (this was confirmed in the semi-structured interviews).

Among the factors that stood out as most positive for the participants was that the cube and audio delivery were seen as playful. The tangible user interface was well received especially in terms of ergonomics and ease of use. This was not a surprise to us since our early testing and participatory design sessions provided us with considerable feedback, especially on ease of use and enjoyment. We went through several iterations and form factors of the wooden cube and tested it against different hand sizes. This may have also resulted in the fact that learning to use the interface and navigation were rated highly and participants felt the system had a low learning curve:

Umm, I found it was really easy. Sometimes I got so engaged in listening to what they were saying that I forgot in which orientation I was holding the cube. And I found that I would have to occasionally look down. But the way it was designed with the round part to go in your palm… it was really easy to quickly reorient myself to how I was holding that cube. (Participant 5)

Interestingly, the audio content was perceived to be both accurate and clear. The issue of trust and delivery style is an area to further investigate.

The questionnaire did point out challenges and areas for further research. Some things we expected such as the headphones were uncomfortable, yet to such a degree that we are currently rethinking the tradeoff between personalized spatial audio and use of headphones. Other results point to a threshold in the balance between levels of abstraction and local information. Since visitors had difficulties at time connecting what they were listening to and what was in front of them (in part this was an inherent challenge in the exhibition since the display cases had dozens to over a hundred artifacts). In addition, we see both a threshold point in play versus focused attention on the exhibit in that the question relating to the content asking if it was "distractive-synergistic" scored 2.83. This raises the issue of balance in play and the possibility to shift attention away from the environment rather than play as a means of further exploring the environment.

It was often remarked how the experience was similar to a game:

The whole system to me felt a lot like a game. I mean I got lost in it, I found myself spending a lot more time in a particular area then I normally would. And just the challenge of waiting to hear what was next, what the little choice of three was going to be. Yeah… So I found it over all engaging, it was fun, and it was very game-like. (Participant 4)

The playfulness did in most instances suggest a quality of engagement that led to learning even through diverse types of museum visits:

I learned a lot and well you know I'm a scientist here, and I think anybody going through, even people who are in a real rush, are going to pick up some interesting facts going through. And… I mean, that was good, the text was great and was short enough that somebody in a rush is still going to catch the whole thing. (Participant 1)

However, we feel a future study in which we compared experiences with and without ec(h)o against visitors' previous knowledge would better measure the degree of learning through use of the system.

As mentioned earlier, there is a threshold between play in support of the exhibit on display and play with the system that can be an end in itself and even a distraction. For example, one user's enthusiasm for the game-like quality led her to at times pay more attention to the interaction with the system than the exhibition. One participant would have preferred a more serious and "non-playful" approach. In addition, participants observations on the *liminality* of the experience manifested in comments suggesting that play was more natural for children rather than themselves, however as expressed they soon overcame this issue:

At first it felt a little bit strange, especially holding this cube that looked like a children's toy, and I felt a little bit awkward about doing that, but I got over that pretty quickly. (Participant 5)

The expert reviews found ec(h)o to be a "pleasurable immersion experience consistent with free-choice leisure learning" establishing its "potential as an effective educational media in a museum setting." The key concerns were the requirement of different audio content for different ages of museum visitors, and occasional "dislocation" of audio content from the artifacts.

DISCUSSION

In this paper we've explored play in a tangible and audio museum guide. Our approach in ec(h)o was to create a coherent space for play and discovery across all components of the design including reasoning, audio delivery and interface. The space suggests actions and meaning but maintains an openness and interpretation that requires playful interaction on the part of the user in order to realize the *action-potential* or relevancy of the information. The results of our ethnography and evaluation of our prototype tell us that play is highly contextual. Designers need to consider the situated nature of play for two reasons: (1) to best serve the overall design purpose; (2) in order to understand the nature and degree of play required.

When is a good thing too much? In our results playfulness was identified positively in all aspects of the interface yet overall satisfaction was split between those participants who enjoyed *playing* and those who did not. Considering who wants to play and who does not is important. The question of too much play is also important. There is a need to find the balance between play in support of the exhibit and play with the system that can be a distraction and even an end in itself. Otherwise designers run the risk of users engrossed in playing with the system at the expense of interacting with their surroundings, as one participant commented happened to her periodically.

What makes sense as play? Playful interaction lends itself well to integrating with the context and in many cases depends on it, as in bouncing a ball off the floor or wall. Yet attempting to bounce our cube off the wall of the museum is not sensible play in a museum. We persuasively designed the cube to be held and not thrown through its shape, tactility and the leash. Moving the cube in one's hand or dangling it from the wrist is seen as *playful* in our museum context – in another context this would be too passive a set of actions to be seen as play. The puns, riddles and word play we used were also contextual. The visitor required the visual artifacts to support the word play and to make sense of the humor. Culture and language make this type of play not for everyone.

What forms of play? Our interface integrated two forms of play: (1) *content play* such as puns and riddles in informational content and used in the audio display; (2) *physical play* that in our case consisted of holding, touching and movement exploring the range and richness of the interaction.

These observations connect us back to the wooden puzzle that fascinated us in our ethnographic study. The puzzle incorporated the forms of content and physical play. It was well balanced with its context providing sensible and engaging play that did not overwhelm its purpose of teaching about collecting natural history artifacts.

CONCLUSION

ec(h)o is an augmented audio reality system for museum visitors that utilizes a tangible interface. We developed and tested the prototype for Canadian Museum of Nature in Ottawa. In ec(h)o we tested the feasibility of audio display and a tangible user interface for ubiquitous computing systems – one that encourages an experience of play and engagement. In this paper we have presented relevant work in the domains of adaptive museum guides and audio displays, ludic approaches to tangible user interfaces, and aesthetic interaction. We provided an overview of our design motivations rooted in ethnography that led to our approaches in audio delivery and tangible interface. We described the components of our prototype and we described our implementation and evaluation.

We found that we could consider play in two main forms in regard to the interface: content and physical play. We also found that play is highly contextual. Designers need to consider the situated nature of play for two reasons: (1) to best serve the overall design purpose; (2) in order to understand the nature and degree of play required.

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