

Designing Opportunistic User Interfaces to Support a Collaborative Museum Exhibit

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Abstract: This research explores how to support collaborative learning practices when science museum visitors employ their own personal mobile devices as *Opportunistic User Interfaces (O-UIs)* to manipulate a simulation-based museum exhibit. The sophisticated graphical capabilities of modern mobile devices have the potential to distract visitors, a phenomenon known as the *heads-down effect*. To study the impact of O-UI design on collaboration, a highly-dynamic “complex” O-UI was contrasted against more simplistic, “remote-control” O-UI design, in the context of a cancer-treatment simulation. As expected, when groups used the “complex” O-UI, there was less visitor-visitor interaction, but unexpectedly, their conversations were of higher quality. They also engaged in better task division and displayed better task performance. The increased attention “simple” O-UI users were able to devote to monitoring one another’s actions seemed to encourage emergent competitive behaviors, which disproportionately affected the engagement of female visitors. “Complex” groups showed no gender-related differences in engagement.

Introduction

The vast majority of visitors to science museums attend in social groups, with one study of 348 of science center visitors revealing that 97% of visitors belonged to family, friend, or school tour groups (Korn, 1995). While at science museums, visitors tend to prefer to engage in shared learning experiences (Borun, 2002; Diamond, 1986; Falk, Scott, Dierking, Rennie, & Cohen Jones, 2004; Paris & Hapgood, 2002). By structuring exhibits to accommodate more than one visitor at a time, museums can further encourage groups of visitors to pause and engage in collaborative learning. The canonical model for a computer-based museum exhibit, however, is that of the kiosk: a desktop computer mounted in a stand-alone housing. With relatively small screens and either a touch-sensitive screen or an input device like a trackball or mouse to provide input, such kiosks really only support use by a single visitor at a time. Improvements in display technology have allowed for the use of very large screens that are easily viewed by multiple visitors at once, but the means by which multiple visitors can provide meaningful simultaneous input are still being experimented with in museums. One possibility is to look to mobile devices. More and more museum visitors are attending museums with mobile computing devices, like cellular phones, in their pockets, and many museums and researchers are interested in taking advantage of the increasingly sophisticated computational, communication, and display capabilities of such devices to enhance the museum-going experience (e.g., Bressler, 2005; Bruns, Brombach, Zeidler, & Bimber, 2007; Haneef & Ganz, 2002; O'Hara, et al., 2007).

The proposal made here is to allow visitors to commandeer their own personal mobile devices into service – using them as impromptu user interfaces to a computer-based exhibit with a large, shared display. Many mobile devices have short-range wireless communication capabilities (like wifi or Bluetooth) that can be used to transmit real-time input to the computer-based exhibit, and in turn real-time output can be transmitted from the computer-based exhibit back to the mobile device, where it can be displayed on the device’s screen. These impromptu user interfaces, dubbed *Opportunistic User Interfaces*, or *O-UIs*, allow computer-based exhibits to scale up to support arbitrarily large groups of mobile-device-toting museum visitors. Moreover, each visitor (assuming he or she is in possession of a mobile device) has equal access to the input and output opportunities made available by the exhibit, thus increasing the group’s symmetry of action (Dillenbourg, 1999). Although access to a shared activity can be considered a *necessary* precondition for collaborative learning to occur, it is not a *sufficient* condition to ensure that collaborative learning will take place. How to design these Opportunistic User Interfaces to encourage groups to take advantage of the provided symmetry of action and become engaged in practices that promote collaboration and collaborative learning is still very much an open question, one which this work begins to address.

The concern is that if visitors use O-UIs to join in a shared collaborative activity, the O-UIs could have the potential to draw so much of the visitors’ visual attention that the exhibit’s public display – and perhaps even the visitors’ companions – become superfluous. Shared public displays can support collaborative learning (e.g., by providing grounding for conversation, and supporting the task monitoring needed for joint attention management), but only if visitors attend to them. So, even if O-UIs allow exhibits to scale up to accommodate groups of visitors, if the O-UIs also put a damper on visitor-visitor interactions, such an exhibit could only nominally be considered supportive of collaborative learning. Museums have had problems in the past with visitors getting so wrapped up in

single-user mobile device applications (e.g., audio/visual guides) that they ignore their surrounding context – an effect known as the “heads-down phenomenon.” There is evidence that increased visual and interactional “complexity” of a mobile device’s user interface may exacerbate the heads-down phenomenon in museums (a notion that will not come as a surprise to parents whose children use mobile gaming devices). It is not known if this phenomenon would occur when *groups* make use of O-UIs, because multi-user activities have a fundamentally different character than single-user activities. The research presented here takes a first slice, contrasting a more “complex” O-UI implementation against a “simple” O-UI implementation, looking to see if the collaborative activities of visitors using O-UIs are negatively impacted by the visual and interactional complexity of the O-UI, while attempting to hold the remainder of the activity constant across implementations.

Background and Prior Work

The Heads-Down Phenomenon and O-UI “Complexity”

The Case Against O-UI “Complexity”

The primary application of handheld devices in museums is in the form of Audio/Visual (A/V) guides, which typically present the same auditory output as regular audio guides, augmented with the addition of visual output in the form of extra text content, images, or video clips [see Raptis, Tselios, Tselios, & Avouris (2005) for a review of the more well-researched A/V guides]. In museums, the presence of advanced multimedia has been shown to cause increases in learning measures like recall and visual recognition tasks (Bellotti, Berta, Gloria, & Margarone, 2002). So, as much as the technology allows, A/V guide designers usually seek to deliver high-quality video, images, and audio to visitors. Unfortunately, A/V guide designers may be victims of their own success – by fully engaging the attention of visitors, such devices serve to distract visitors from other elements of their museum experience.

Studies of an A/V guide dubbed the *Electronic Guidebook* at the Exploratorium, a hands-on science center in San Francisco, found that a large majority of visitors reported experiencing feelings of isolation, with some also reporting that because of their usage of the device, they were prevented from interacting with their human companions (Hsi, 2003). To quote one visitor: “I didn’t really notice other people; I wasn’t paying attention to anybody except for reading the screen” (Hsi, 2002). An observational study of A/V guide use at an aquarium confirmed these visitor perceptions: those visitors who engaged with AV guides were observed to be much more isolated than the average visitor (Bellotti, et al., 2002). This is a finding that paralleled the observations of an earlier study that noted that some visitors got “lost in hyperreality,” and ceased paying attention to the surrounding context in favor of attending to the handheld device (Fleck, et al., 2002). The ability of handheld devices to usurp visitors’ attention has been reported in other forums, to the degree where it’s been given a name in museum practitioner circles: the “heads-down phenomenon” (Exploratorium, 2005; Walter, 1996; Wessel & Mayr, 2007).

A sign that the visual output of A/V devices may be primarily to blame for the heads-down phenomenon comes from (Bellotti, et al., 2002), who found that some visitors would willfully ignore the visual output of the devices, essentially using them as audio-only guides, so that they could pay more attention to the rest of the museum experience. In another A/V guide study, visitors were observed to get lost in the heads-down phenomenon predominantly when using a highly interactive “mini-game” (Thom-Santelli, Boehner, Gay, & Hembrooke, 2006). The evidence seems to imply that the use of mobile devices, and especially mobile devices with interactive visual output, may interfere with visitors’ ability to attend to their companions, and, in turn, their ability to engage in collaborative learning with their companions while engaged in synchronous, co-located, highly-interactive activities.

Multi-User Activities and O-UI “Complexity”

The prior section discussed the heads-down phenomenon in the context of A/V guides, which are largely designed to be *single-user* activities. Much less information is available on the impact of mobile interface “complexity” on users when the activity has been designed explicitly to be *multi-user*. When mobile devices have been used to support synchronous (same time) co-located (same place) group activities in museums, they have been employed to allow visitors to choose between being supplied individualized or shared information about an exhibit (e.g., Aoki, et al., 2002; Grinter, et al., 2002; Kruppa, Lum, Niu, & Weinel, 2005; Woodruff, Szymanski, Aoki, & Hurst, 2001), or engage in cooperative treasure-hunt style activities (e.g., Klopfer, Perry, Squire, & Jan, 2005; Yatani, Sugimoto, & Kusunoki, 2004) or quiz activities (e.g., Thom-Santelli, et al., 2006; Yatani, et al., 2004). Apart from (Thom-Santelli, et al., 2006), none of these studies hinted that visually-rich, highly-interactive mobile displays would lead to the heads-down effect. In the author’s own work studying the collaborative use of O-UIs in a *classroom* context, middle-school students exhibited no great difficulty in shifting their attention between the handheld device and the rest of the shared context (Lyons, Lee, Quintana, & Soloway, 2006a, 2006b), even though the O-UIs they were

using featured many dynamic graphical elements. Perhaps the social context is enough to ameliorate the heads-down phenomenon, regardless of the degree of O-UI complexity? The lack of clarity concerning whether or not the heads-down phenomenon would impair collaborative learning in the context of multi-user activities sparked the design of the experimental study reported in this paper.

Software Design

The experimental research reported on here was conducted as a smaller part of a larger Design-Based Research project (Barab, 2006; Brown, 1992) which had both a prospective (forward-looking) and a reflective (or evaluative) phase (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). The first phase of the project involved extensive *in situ* formative testing on the floor of a hands-on science museum, the Exploratorium in San Francisco. The purpose of the formative phase was to produce a computer-based testbed exhibit and Opportunistic User Interface designs that would have high external validity. This paper reports only on the second, reflective phase of the project, which was a controlled, experimental study that evaluated the use of a “simple” O-UI design against a “complex” O-UI design.

Activity Testbed Design

A “testbed” exhibit that would allow for multi-user interactions needed to be developed, but to be in keeping with the spirit of DBR, it was important that the testbed be a *plausible* museum exhibit (i.e., that it would have a high external validity). Hands-on science museums (unlike art or history or even natural history museums) do not usually present objects (like paintings, or artifacts, or fossils) to visitors. Rather, they present *phenomena* to visitors, by constructing hands-on exhibits that allow visitors to directly interact with phenomena like gravity, electricity, or human visual perception. Although computers cannot present phenomena directly, via *simulations* of real-world phenomena, computer-based exhibits can give visitors the same degree of interaction and experimentation provided by more traditional hands-on physical exhibits. For this reason, a simulation was chosen as the core of the testbed activity. The particular *type* of simulation (cellular automata) was chosen because it allows for emergence of patterns of similar outcomes, without ever showing the exact same “result” twice: this is in keeping with the richness of outcomes possible with physical hands-on exhibits.

The first, and simplest, cellular automata simulation created was Conway’s *Game of Life*, wherein white and black dots in a grid swap colors based on a simple rule set (Gardner, 1970). The *Game of Life* is very abstract, so to create the testbed exhibit, its rules were expanded upon to present a more contextualized phenomenon: a simulation of cancer growth in human tissue. The simulation uses a grid of interconnected cells to represent the “patient” suffering from cancer. The cells are placed at the intersections of a grid, connected by blood vessel segments (see Figure 1). All cells are dependent on blood flow for survival, but they share blood vessels and thus implicitly compete for blood supply. As automata, each element of the simulation (each cancer cell, each healthy cell, and each blood vessel segment) maintains information about its current state in the form of variables, but shares a rule base with other automata of its type (i.e., all healthy cells obey the same set of rules, all blood vessel segments obey their own shared set of rules, etc.). There is no “controlling hand” to the simulation – the next state of the simulation is an outgrowth of each automaton performing its own state update.

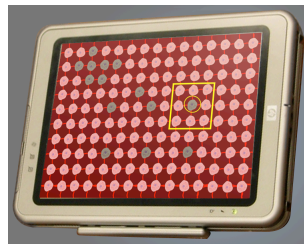


Figure 1. The cancer growth simulation (for the experiment, a large plasma screen was used in lieu of the tablet PC depicted here). Cells are arranged in a grid, connected via blood vessels. Clusters of the darker cancer cells act as “tumors.” The rectangle is the “incision” of a player, which can be moved from place to place.

Implemented in this manner, the simulation is relatively simple in its definition, but nonetheless exhibits several complex emergent phenomena that are hallmarks of cancer in real life: tumor growth and its associated angiogenesis, metastasis, and radiation-induced secondary cancers. Another advantage of implementing the simulation as a complex system simulation is that each “run” of the simulation is unique: although common patterns (like tumors) emerge, they do so in different locations each time. This adds to the replayability of the simulation, and to its educational value. When learning from simulations, “the main task of the learner [is] to infer, through

experimentation, characteristics of the model underlying the simulation” (de Jong & van Joolingen, 1998). By ensuring that there are no “surface-level” patterns to master (for example, if the simulation were to follow a set, predictable pattern where the tumor always begins in the upper-left quadrant) learners are forced to understand the “deep-level” mechanisms. For example, the role blood supply plays in supporting the growth of tumors.

Visitors interact with the simulation by attempting to eliminate the cancer from the simulated patient. The simulation is tuned so that no single user can eliminate cancer alone – they must work together to accomplish the task. The intent was to support a version (albeit limited to divide-and-conquer strategies) of the jigsawed role-playing that was shown to be so successful at encouraging visitor-visitor interaction in (Klopfer, et al., 2005).

O-UI Design

HP iPaq h4100 handheld devices were used as a proxy for whatever devices a visitor may have with them when they attend the museum, as it was important to ensure that the devices be held constant for the experiment. Visitors were restricted a single role, Surgery, in an attempt to keep the activity as constant as possible across the two conditions, apart from how the O-UI design itself would alter the visitors’ perception of the activity. Two O-UI designs were created and refined for the Surgery role: one which made extensive use of the touch-sensitive display screen (the “complex” O-UI), and one which operated more like a “remote control” (the “simple” O-UI) to serve as a baseline (without an interactive display to become engrossed in, “simple” O-UI users should not exhibit the heads-down phenomenon). Extensive formative testing on the floor of the Exploratorium helped refine these competing interfaces so that they would be easy-to-use in their own right (so that the experiment would not be a straw-man test) and so that they would have equivalent impact on the simulation (i.e., one O-UI design would not have a functional advantage as compared to the other; a process known as play-balancing in the field of computer game development).

After using an O-UI to log into the simulation, a small color-coded rectangle, labeled with the user’s name, appears on the large plasma screen depicting the simulation overview (see Figures 1 and 3). Players are able to distinguish one another’s representations on the shared screen using color-coding, a fairly standard approach in collaborative entertainment software (Bricker, Baker, Fujioka, & Tanimoto, 1998). The color-coded rectangle is an analogue to the “incision” that a surgeon can make into a patient, with the exception that this “incision” can be relocated by pressing the directional control pad buttons on the handheld device. When the surgery player makes “cuts” in the incision area, the cells and blood vessel segments underneath the “cuts” take damage.

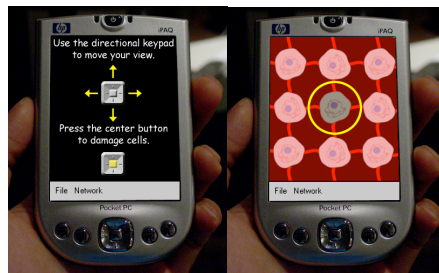


Figure 2. On the left is the “simple” O-UI design. The image on-screen is a static placeholder. On the right is the “complex” O-UI design, which displays a detailed view of the cells within the “incision rectangle.” The circle indicates where the user has drawn with the stylus to “cut” out the cancer cell in the middle of the display.

The “Simple” Surgery O-UI

The “simple” Surgery O-UI was originally designed to emulate a remote control, and thus did not make use of the display. Formative testing showed visitors were confused by the blank screen, and so a static instruction screen was substituted (see Figure 2). All input is provided via hardware buttons: the control pad “steers” the incision rectangle around the shared display, and the center button initiates an excision that damages cells within a certain radius. The amount and distribution of damage was tuned to be in keeping with the average damage patterns administered by “complex” O-UI users, so that the impact of “simple” and “complex” O-UIs on the simulation was equivalent.

The “Complex” Surgery O-UI

The “complex” Surgery O-UI was deliberately designed to occupy as much of the visitor’s visual attention as possible, to maximize the severity of the “heads-down” phenomena should it occur in the context of a multi-user shared activity. Although “complex” users “steer” the incision rectangle in the same manner as “simple” users (with the control pad), surgery is performed by drawing circles on the touch-sensitive screen with a stylus, which (a)

reflects an input style that is becoming increasingly common in mobile devices, and (b) maximizes the visual attention load, as hand-eye coordination is required from visitors in order to provide input.

Experimental Design

The experiment contrasted a “simple” O-UI condition against a “complex” O-UI condition, to determine the extent to which the heads-down phenomenon emerged in the latter condition, and if any differences in conversation patterns or task performance could be found that would correlate with heads-down behaviors. An “incomplete” repeated-measures design with rotation was used, meaning that each group experienced *both* of the experimental conditions, but the order of exposure was rotated to fully counterbalance any practice effects (Shaughnessy, Zechmeister, & Zechmeister, 2008).

Setting and Participants

The lab used for the experiment was a small, controlled room adjacent to the museum floor, created for use by the in-house Visitor Research and Evaluation group, and outfitted with state-of-the-art audio/visual recording equipment (see Figure 3). All user input actions were logged, as was each state update of the simulation. Groups of visitors were recruited through the museum’s newsletter and from the floor of the museum, using a policy wherein *any* group with 3 or more members was approached to participate in an attempt to get a representative sample of the types of groups present in museums. Eleven groups were recruited: 4 were mixed-age families, and 7 were groups of friends, and the average group size was 3.3. The average age was 26 (the youngest was 10 and the oldest was 59, with a median age of 20). The gender ratio was roughly 45:55 female:male, with above 80% of the groups having mixed gender composition.

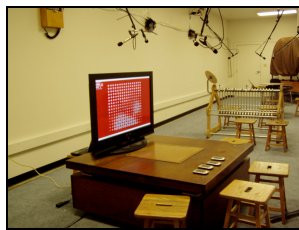


Figure 3. Photograph of the experimental setup: the 4’ plasma screen used as a shared display and the handheld computers used by participants, as well as the stools used for seating. The hanging microphones used to capture audio are visible, and the structure mounted on the wall behind the plasma screen is the primary video camera.

Measures

Gaze as an Indicator of the “Heads-Down Phenomenon”

The name of the “heads-down phenomenon” suggests that users spend a majority of time gazing “down” at their mobile devices. The video was used to code the moment-by-moment gaze target for each visitor. The *Proportion* and *Duration* of gazes directed at the mobile devices were then calculated.

Conversation as an Indicator of Collaboration

The first coding pass differentiated *on-task* utterances (those relevant to the collaborative activity at hand) from *off-task* utterances to separate out participants who are actively engaged from those who are merely socially engaged, or chatty (Hertz-Lazarowitz, 1992). Although *on-task/off-task* binning indicates something about base levels of engagement in the shared task, two further passes were used to examine the on-task utterances. One was to determine how the utterances relate to the joint task execution (a *functional* perspective), and the other was to determine how the utterances relate to the context of the group’s shared knowledge building (an *interactional* perspective). The *functional* pass attempted to single out on-task utterances for their potential to make a tactical or strategic impact on the group’s behavior. Many utterances contain both tactical and strategic content, so a *Tactical/Strategic* versus *Nontactical/Nonstrategic* coding was used. The *Tactical/Strategic* category is very similar to the interpreting/applying category used in (Borun, Chambers, & Cleghorn, 1996), where family conversation utterances in museums were binned into three levels of learning: identifying, describing, and interpreting/applying.

Collaborative learning researchers often look for *interaction* patterns within conversational exchanges, to see if, for example, learners build upon each other’s ideas (Palincsar & Herrenkohl, 1999). In a study that contrasted groups that succeeded collaboratively against those that failed, both *building upon* one another’s comments and *echoing* one another’s remarks were seen as precursors to effective collaborative learning (Barron, 2000). A related

measure, *conversational elaboration*, is often used to study learning in museums (Paris & Hapgood, 2002). *Explanation-giving* is another conversational behavior often linked to effective collaborative learning (Bargh & Schul, 1980; Webb, 1984), and *explanation quality* has been found to correlate positively with small-group learning outcomes in classrooms (Webb, 1989). For the purposes of this study, *on-task* utterances were further classified as either *New Statements*, meaning that a conversational antecedent could not be found, *Responses*, meaning that the speaker is replying to or referencing an utterance made by a companion, and *Continuations*, meaning that the speaker is following up on an utterance he or she made previously. The proportion of *Responses* and *Continuations* made by group members can be taken together to provide a rough metric for collaborative conversation quality.

Shared Task Performance as an Indicator of Collaboration

Shared task performance can be measured by examining the actions users take within the activity. For example, if a participant damages more healthy cells than cancer cells, it can be safely said that the participant does not understand (or has a perverse desire to undermine) the shared task: to eliminate cancer cells from the simulated patient. An advantage to adopting a game-like activity structure for a learning activity is that there are often built-in measures of task performance: when users must attain some of the learning goals to be able to successfully complete the tasks, the task performance measures can serve as a sort of proxy for measuring learning (Lyons & Pasek, 2006).

Using the *individual* as the unit of analysis is a mainstay of traditional education, but to truly understand a collaborative learning context, the level of granularity needs to be that of the *group*, and measures need to be used that take into account group-level processes and structures (Greeno, 2006). Some educational researchers have begun using the concept of *participation equity* as a measure of the success or failure of the collaborative aspect of an activity (Kapur & Kinzer, 2007), a concept that has also been labeled “mutuality” (Barron, 2000). The rationale is that a group activity that encourages only *one* member of the group to pay attention, be engaged, or perform well cannot be considered a successful collaboration. For that reason, the participation equity of groups is taken into account: the assumption being that the higher the equity, the better the activity is at supporting collaboration.

A related concept is that of *task division*: in a collaborative activity, participants should be able to divide the task in a manner appropriate to that particular joint activity. Owing to the distribution and relatively fast spread of cancer cells in the simulated patient, the effective task division strategy for this experiment is a spatial divide-and-conquer strategy. This can be measured by the degree to which participants avoid overlapping their incision rectangles with their partners’ rectangles. The *ownership degree* is the proportion of time a participant’s incision does not overlap partners’ incisions. So if a participant *never* overlapped his or her incision rectangle with other players, he or she would have an *ownership degree* of 1. The *ownership degree* is also weighted by the number of overlapping partners. So if two players overlapped incisions with others for the same length of time, but one player overlapped with two or more partners a majority of the time, he or she would have a lower *ownership degree* than a player whose overlaps involved only a single other player.

Results

Gaze as an Indicator of the “Heads-Down Phenomenon”

The “complex” gaze patterns conform to prior anecdotal accounts of the heads-down phenomenon. There are no empirical results in the literature to indicate the boundaries beyond which gaze behaviors are categorized as heads-down, so the difference found here is reported to give the reader a sense of the span between the two extremes: the “baseline” established by the “simple” condition, and the intentional “worst-case” of the “complex” condition. *Proportionally*, more than half (66%) of “complex” user gazes were directed at the device (32% were devoted to the shared display) and the average *Duration* of gazes directed at devices was 13 s (compared to 3 s devoted to the shared display). When the same users were in the “simple” condition, the device captured only 14% of gazes (83% were devoted to the shared display) for an average of 3 s at a stretch (whereas shared display gazes lasted 21s).

Conversation as an Indicator of Collaboration

The analysis of raw conversational frequency indicates that, as the absence of the heads-down phenomenon might predict, “simple” O-UI participants have a significantly higher level of conversational frequency, about 6 utterances per minute as compared to about 4.5 per minute for “complex” users (see Table 1). The magnitude of the difference is not terribly large, and further analysis of the coded utterances reveals that, surprisingly, “complex” users engage in proportionally more *on-task* and *functional* talk, differences that are statistically significant. Nearly half of all utterances made by “complex” participants were on-task, compared to around one third for “simple” participants. There was effectively no difference in the proportion of *interactional* talk between the two conditions, however. What this indicates is that although participants converse less while using a more visually-distracting O-UI, they are

no less likely to respond to one another – the continuity of conversation is not affected. The results show that a more “complex” O-UI, despite encouraging heads-down gaze behaviors and depressing overall conversation frequency, may actually *better* support collaborative learning, by discouraging *off-task* and *non-functional* talk. (Inter-coder reliability between the author and a second coder, after resolution of disagreements, was 94.4% for *On-task* coding, and subsequently 91.9% for *Functional* and 99.97% for *Interactional* coding on a previously uncoded transcript).

Table 1. Comparisons of overall conversational frequencies and proportions of coded utterances.

Dependent Variables	“Simple” O-UI Participants <i>n</i> = 31	“Complex” O-UI Participants <i>n</i> = 31	Significance (paired <i>t</i> test), <i>n</i> = 62, <i>df</i> = 30
Conversation Frequency (utterances per minute)	<i>M</i> = 6.07 (<i>SD</i> = 2.73)	<i>M</i> = 4.51 (<i>SD</i> = 2.62)	<i>t</i> (30) = 4.32***
On Task Proportion	<i>M</i> = 0.36 (<i>SD</i> = 0.18)	<i>M</i> = 0.49 (<i>SD</i> = 0.17)	<i>t</i> (30) = 4.04***†
On Task: Functional Proportion	<i>M</i> = 0.21 (<i>SD</i> = 0.14)	<i>M</i> = 0.30 (<i>SD</i> = 0.19)	<i>t</i> (30) = 2.79**†
On task: Interactional Proportion	<i>M</i> = 0.47 (<i>SD</i> = 0.20)	<i>M</i> = 0.49 (<i>SD</i> = 0.19)	(none)

p* < .01, *p* < .001, † two-tailed test

Task Performance

Task Division

Because “simple” players attended more to the shared display, one might expect that they would be better at dividing the joint task, and thus have a higher *ownership degree*. Recall that if a participant never overlapped his or her incision rectangle with other players, he or she would have an *ownership degree* of 1: “simple” players had a middling *ownership degree* (*M* = 0.55, *SD* = 0.13), whereas “complex” players had significantly higher *ownership degree* (*M* = 0.71, *SD* = 0.15), paired *t*(30) = 5.59, *p* < 0.00001, two-tailed. From this evidence, it seems that “complex” players are better at engaging in task division. This echoes anecdotal observations made during the experiments: it seemed as though participants in the “simple” condition, rather than using the shared display to better coordinate their task division efforts, would instead rush to move their incision rectangles to the same places as their partners’ rectangles and then target the same cancer cells. The players seemed to be uninterested in the coordinative aspects of the joint task in the “simple” condition. Oddly, the same players engaged in better task division in the “complex” condition, despite increased heads-down gaze behaviors, indicating that joint task monitoring is not automatically promotive of improved collaboration in the context of a shared computer-based museum exhibit.

Task Execution

Players also seemed less aware of, or less interested in, the underlying mechanisms of the simulation when in the “simple” condition. On a measure that compared damage done to cancer cells versus healthy cells, “complex” participants (*M* = 0.74, *SD* = 0.17) outperform “simple” participants (*M* = 0.17, *SD* = 0.29) four-to-one, paired *t*(30) = 10.10, *p* < 3.7 E-11, two-tailed. This may be due to the poor task division of the “simple” participants: trying to compete to eliminate the same few cancer cells resulted in much higher collateral damage to nearby healthy cells.

Participation Equity

Participation Inequity (PI), a concept borrowed from (Kapur & Kinzer, 2007), takes the within-group standard deviation (*SD*) to compute a measure of how *dissimilar* group members are from one another in their individual participation. So, if one group member dominates the activity by making the majority of moves, the within-group standard deviation of the number of moves made by each group member would be high. Examining the *PI*, we see that the within-group *move inequity* in the “simple” condition is larger on average (*M* = 16.3, *SD* = 15.8) than when the same groups were in the “complex” condition, (*M* = 5.68, *SD* = 2.92). It is also curious that the variance in *PI* across groups (i.e., group-to-group variance in inequity) was higher in the condition with higher visual monitoring (the “simple” condition). Utterances made by female players while using the “simple” O-UI seem to indicate that the variance may be related to gender. The following transcript is from when a group transitioned from the “complex” to the “simple” condition, and follows two older female speakers (East and South):

- East:** “Yeah, this is more like a teenage boy thing cause you gotta have that eye - uh”
South: “Yeah, pow pow pow” <Laughs>
East: “But you gotta move around really fast, you know what I mean? They're good at that.”
South: “Yeah I know.”

East: “I’m not as good at it.”

East: [addressed to West] “Ok, you got em! You guys could do this game by yourself...”

A *post-hoc* analysis seems to show that gender does indeed have a modifying effect on the move frequency measure. While females and males are very similar to one another in their move frequencies in the “Complex” condition ($M=19.8$, $SD = 7.96$, and $M = 21.7$, $SD = 10.3$, respectively, a difference of only 1.9 moves per minute), they show very different move frequencies in the “simple” condition ($M=42.8$, $SD = 21.4$, and $M = 64.0$, $SD = 25.8$, respectively, a difference of 23.2 moves per minute – ten times greater than the move frequency difference in the “complex” condition). Merely looking at these descriptive statistics is enough to show that there are stark gender-related differences for the “Simple” participants. What is not apparent from either dialogue or statistics is that after making her final remark (“...You guys could do this game by yourself...”) East set down her handheld device, followed soon after by the other female participant, South, whereupon both stopped participating in the activity. This behavior – a participant putting down an O-UI – was never observed with a male participant, and was never observed with female participants in the “complex” condition, but was observed several times, for varying lengths of time, among females in the “simple” condition. Judging by the remarks quoted above, it seems that the increased monitoring of one’s partners’ actions in the “simple” condition lead to inevitable performance comparisons, and, in turn, to emergent competitive behaviors that may have intimidated females.

Conclusion and Future Work

Computer-Supported Collaborative Work researchers have long promoted the use of large, shared displays to encourage collaboration in shared settings (e.g., Stewart, Bederson, & Druin, 1999). In a work context, the ability to monitor the actions of one’s companions was seen as an asset to collaboration, enabling co-workers to better coordinate. In the context of collaborative learning in classrooms, making the performance of individual partners public is often seen as a method to encourage all group members to participate in the joint learning activity, and discourage social loafing (e.g., Slavin, 1992). In this informal learning context, however, increased monitoring of one’s partners does not seem to spur an improvement in collaborative practices.

The evidence here shows that while increased O-UI “complexity” may indeed cause users engage in gaze behavior consistent with the heads-down phenomenon, this decreased monitoring did not unduly impede collaborative practices. Participants spoke somewhat less while using the “complex” O-UI, but were just as responsive to one another as they were in the “simple” condition. Participants were more likely to make utterances that were *on-task* and focused on the *functional* aspects of the joint task when using the “complex” O-UI, which implies they were more focused on accomplishing the joint task. The task performance analyses confirm this: “complex” participants showed better *task execution*, showing that they better understood the underlying simulation mechanics, engaged in better *task division*, and showed better *participation equity*. The fact that the emergent competition seen with the use of remote-control-like O-UIs disproportionately affected the degree of female participation is of particular concern to museums, which must serve a wide variety of demographics. When O-UIs with interactive displays were used, however, gender-based differences in participation disappeared.

Thus, the “complex” O-UIs used here showed better support for collaborative learning activities despite being explicitly designed to encourage heads-down gaze behaviors. This suggests that the heads-down phenomenon is not as problematic for multi-user activities as it has been found to be for single-user activities in museums, giving designers permission to consider using mobile displays when designing O-UIs for collaborative activities. The experimental phase of research reported on here was followed by another “prospective” phase of DBR to more fully explore the design possibilities “complex” O-UIs make available. During this prospective phase, additional player roles were developed to complement the Surgery role, with the goal of supporting more of a true jigsaw-style collaboration between visitors. Trials conducted on the floor of the museum are still under analysis, but preliminary results suggest that providing orthogonal roles encourages deeper discussions of the underlying simulation rules.

References

- Aoki, P. M., Grinter, R. E., Hurst, A., Szymanski, M. H., Thornton, J. D., & Woodruff, A. (2002). *Sotto voce: exploring the interplay of conversation and mobile audio spaces*. Proceedings of the SIGCHI conference on Human factors in computing systems (CHI '02), Minneapolis, Minnesota, USA.
- Barab, S. (2006). Design-Based Research: A Methodological Toolkit for the Learning Scientist. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences*. New York, NY, USA: Cambridge University Press.
- Bargh, J. A., & Schul, Y. (1980). On the cognitive benefits of teaching. *Journal of Educational Psychology*, 72(5), 593-604.

- Barron, B. (2000). Achieving coordination in collaborative problem-solving groups. *The Journal of the Learning Sciences*, 9(4), 403-436.
- Bellotti, F., Berta, R., Gloria, A., & Margarone, M. (2002). User testing a hypermedia tour guide. *Pervasive Computing*, 1(2), 33-41.
- Borun, M. (2002). Object-Based Learning and Family Groups. In S. G. Paris (Ed.), *Perspectives on object-centered learning in museums* (pp. 245-261). Mahwah, N.J. :: L. Erlbaum Associates.
- Borun, M., Chambers, M., & Cleghorn, A. (1996). Families are learning in science museums. *Curator*, 39(2), 262-270.
- Bressler, D. M. (2005). *Science Now, Science Everywhere: Liberty Science Center's Mobile Learning Companion* (White paper): Liberty Science Center.
- Bricker, L. J., Baker, M., Fujioka, E., & Tanimoto, S. (1998). *Colt: A System for Developing Software that Supports Synchronous Collaborative Activities*: University of Washington Technical Report.
- Brown, A. L. (1992). Design Experiments: Theoretical and Methodological Challenges in Creating Complex Interventions in Classroom Settings. *The Journal of the Learning Sciences*, 2(2), 141-178.
- Bruns, E., Brombach, B., Zeidler, T., & Bimber, O. (2007). Enabling Mobile Phones To Support Large-Scale Museum Guidance. *Multimedia*, 14(2), 16-25.
- Cobb, P., Confrey, J., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design Experiments in Educational Research. *Educational Researcher*, 32(1), 9-13.
- de Jong, T., & van Joolingen, W. R. (1998). Scientific Discovery Learning with Computer Simulations of Conceptual Domains. *Review of Educational Research*, 68(2), 179-201.
- Diamond, J. (1986). The Behavior of Family Groups in Science Museums. *Curator: The Museum Journal*, 29(2), 139-154.
- Dillenbourg, P. (1999). What do you mean by collaborative learning? In P. Dillenbourg (Ed.), *Collaborative Learning: Cognitive and Computational Approaches* (pp. 1-15). Oxford: Elsevier.
- Exploratorium (2005). Electronic Guidebook Forum [Online]. 66. Retrieved from <http://www.exploratorium.edu/guidebook/>
- Falk, J. H., Scott, C., Dierking, L., Rennie, L. J., & Cohen Jones, M. (2004). Interactives and Visitor Learning. *Curator*, 47(2), 171-198.
- Fleck, M., Frid, M., Kindberg, T., O'Brien-Strain, E., Rajani, R., & Spasojevic, M. (2002). From informing to remembering: ubiquitous systems in interactive museums. *Pervasive Computing*, 1(2), 13-22.
- Gardner, M. (1970, October, 1970). Mathematical Games: The fantastic combinations of John Conway's new solitaire game "life". *Scientific American*, October, 1970.
- Greeno, J. G. (2006). Learning in Activity. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences*. New York: Cambridge University Press.
- Grinter, R. E., Aoki, P. M., Hurst, A., Szymanski, M. H., Thornton, J. D., & Woodruff, A. (2002, November 2002). *Revisiting the visit: understanding how technology can shape the museum visit*. Proceedings of CSCW, New Orleans, Louisiana, United States.
- Haneef, A. M., & Ganz, A. (2002). *Mobile agent based network access for mobile electronic guidebooks*. International Mobility and Wireless Access Workshop (MobiWac '02).
- Hertz-Lazarowitz, R. (1992). Understanding Interactive Behaviors: Looking at Six Mirrors of the Classroom. In R. Hertz-Lazarowitz & N. Miller (Eds.), *Interaction in cooperative groups. The theoretical anatomy of group learning* (pp. 174-199). New York, NY: Cambridge University Press.
- Hsi, S. (2002). *The Electronic Guidebook: A Study of User Experiences using Mobile Web Content in a Museum Setting*. Proceedings of the International Workshop on Wireless and Mobile Technologies in Education (WMTE '02), Växjö, Sweden.
- Hsi, S. (2003). A study of user experiences mediated by nomadic web content in a museum. *Journal of Computer Assisted Learning*, 19(3), 308-319.
- Kapur, M., & Kinzer, C. (2007). Examining the effect of problem type in a synchronous computer-supported collaborative learning (CSCL) environment. *Educational Technology Research and Development*, 55(5), 439-459.
- Klopfer, E., Perry, J., Squire, K., & Jan, M. (2005). *Mystery at the Museum – A Collaborative Game for Museum Education*. Proceedings of the conference on Computer Supported Collaborative Learning (CSCL '05), Taiwan.
- Korn, R. (1995). An analysis of differences between visitors at natural history museums and science centers. *Curator*, 38(3), 150-160.

- Kruppa, M., Lum, A., Niu, W., & Weinel, M. (2005, June 24-25, 2005). *Towards Mobile Tour Guides Supporting Collaborative Learning In Small Groups*. Workshop on New Technologies for Personalised Information Access at User Modeling, Edinburgh, UK.
- Lyons, L., Lee, J., Quintana, C., & Soloway, E. (2006a). *MUSHI: A Multi-Device Framework for Collaborative Inquiry Learning*. Proceedings of the International Conference of the Learning Sciences (ICLS2006), Bloomington, IN, USA.
- Lyons, L., Lee, J., Quintana, C., & Soloway, E. (2006b). *Preliminary Evaluation of a Synchronous Co-located Educational Simulation Framework*. Extended Abstracts of the 2006 Conference on Human Factors in Computing Systems (CHI 2006), Montreal, CA.
- Lyons, L., & Pasek, Z. (2006, June 18-21, 2006). *Gauging Visitor Behavior at an Interactive Engineering Exhibit*. Proceedings of the 2006 Conference of the American Society for Engineering Education (ASEE '06), Chicago, IL.
- O'Hara, K., Kindberg, T., Glancy, M., Baptista, L., Sukumaran, B., Kahana, G., et al. (2007). Collecting and Sharing Location-based Content on Mobile Phones in a Zoo Visitor Experience. *Computer Supported Cooperative Work*, 6(1-2), 11-44.
- Palincsar, A. S., & Herrenkohl, L. R. (1999). Designing Collaborative Contexts: Lessons from Three Research Programs. In A. M. O'Donnell & A. King (Eds.), *Cognitive Perspectives on Peer Learning* (pp. 151-177). Mahwah, NJ: Lawrence Erlbaum.
- Paris, S. G., & Hapgood, S. E. (2002). Children Learning with Objects in Informal Learning Environments. In S. G. Paris (Ed.), *Perspectives on object-centered learning in museums* (pp. 37-54). Mahwah, N.J. :: L. Erlbaum Associates.
- Raptis, D., Tselios, N., Tselios, N., & Avouris, N. (2005). *Context-based design of mobile applications for museums: a survey of existing practices*. MobileHCI '05: Proceedings of the 7th international conference on Human computer interaction with mobile devices & services, Salzburg, Austria.
- Shaughnessy, J. J., Zechmeister, E. B., & Zechmeister, J. S. (2008). *Research Methods in Psychology* (8 ed.). New York, NY: McGraw-Hill.
- Slavin, R. E. (1992). When and Why Does Cooperative Learning Increase Achievement? Theoretical and Empirical Perspectives. . In R. Hertz-Lazarowitz & N. Miller (Eds.), *Interaction in cooperative groups. The theoretical anatomy of group learning* (pp. 174-199). New York: Cambridge University Press.
- Stewart, J., Bederson, B. B., & Druin, A. (1999, May 15-20). *Single display groupware: a model for co-present collaboration*. Proceedings of the SIGCHI conference on Human factors in computing systems: the CHI is the limit, Pittsburgh, Pennsylvania, United States.
- Thom-Santelli, J., Boehner, K., Gay, G., & Hembrooke, H. (2006). *Beyond just the facts: transforming the museum learning experience*. CHI '06: CHI '06 extended abstracts on Human factors in computing systems, Montreal, Quebec, Canada.
- Walter, T. (1996). From museum to morgue? Electronic guides in Roman Bath. *Tourism Management*, 17(4), 241-245.
- Webb, N. M. (1984). Stability of small group interaction and achievement over time. *Journal of Educational Psychology*, 76(2), 211-224.
- Webb, N. M. (1989). Peer interaction and learning in small groups. *International Journal of Educational Research*, 13, 21-39.
- Wessel, D., & Mayr, E. (2007). Potentials and Challenges of Mobile Media in Museums. *International Journal of Interactive Mobile Technologies*, 1(1), 1-8.
- Woodruff, A., Szymanski, M. H., Aoki, P. M., & Hurst, A. (2001). *The Conversational Role of Electronic Guidebooks*. Proceedings of the 3rd international conference on Ubiquitous Computing, Atlanta, Georgia, USA.
- Yatani, K., Sugimoto, M., & Kusunoki, F. (2004). *Musex: A System for Supporting Children's Collaborative Learning in a Museum with PDAs*. Proceedings of the IEEE International Workshop on Wireless and Mobile Technologies in Education (WMTE'04), Taoyuan, Taiwan.

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