Lessons Learned: Game Design for Large Public Displays

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ABSTRACT
This paper presents the design and deployment of *Polar Defence,* an interactive game for a large public display. We designed this display based on a model of "users" and their interactions with large public displays in public spaces, which we derived from prior work. We conducted a four-day user study of this system in a public space to evaluate the game and its impact on the surrounding environment. Our analysis showed that the installation successfully encouraged participation among strangers, and that its design and deployment addressed many of the challenges described by prior research literature. Finally, we reflect on this deployment to provide design guidance to other researchers building large interactive public displays for public spaces.

Categories and Subject Descriptors
H5.m Information interfaces and presentation (e.g. HCI), H5.2 User interfaces-Graphical user interface.

General Terms
Design, Experimentation and Human Factors.

Keywords
Interactive large public displays, personal devices, cell phones, short messages services (SMS), shared entertainment, gaming, user study.

1. INTRODUCTION
The role of large displays in public spaces is evolving, due in large part to the increasingly sophisticated technology that drives these displays. Initially, large, static billboards provided *location-relevant* information (such as maps on shopping mall directories) or advertising. As technology came to enable dynamically changing information, we began to see large displays show *time-relevant* information (such as departure/arrival times in airports or train stations), in addition to location-relevant information. Even more recently, we have begun to see dynamic digital displays in public spaces, often for the purpose of entertaining large audiences. For instance, organizers of 2006 Soccer World Cup placed large display installations outside of venues, and these displays attracted literally thousands of viewers who stayed and watched entire games outside the stadiums. These displays, placed in such public spaces, were able to deliver a joint entertainment experience among audience members, something that is not possible in, for example, a home environment. Thus, the role of these large public displays has also begun to include *shared entertainment*.

Parallel to their use in public spaces, we have seen large displays being developed and deployed as semi-public displays in work contexts (e.g. Huang et al. [11]). These displays share many characteristics: they are often interactive, mainly developed for groupware applications, and focused on work. Examples of such systems include the MERBoard [11], BlueBoard [17], or SMART Technologies' SMARTBoard [18]. These interactive large display installations are distinct from the public displays we described earlier in three major ways: first, they primarily serve a collaborative work environment (which means group members roles may aid in coordinating and organizing use and access of such displays); second, these groups usually have a common understanding or goal in their use of the displays; and finally, the users making use of the display are generally a fixed set of known individuals (e.g. Huang and Mynatt [12]).

Our work explores the intersection of these trends: the increasing use of large displays in public spaces for shared entertainment and to support multi-user interactivity. Our interest is in understanding how a large interactive display placed in a public space can augment or transform the space, or influence its inhabitants (e.g. Karahalios [13]). What role can such a display take on in a public space? Addressing such questions raises several design questions: How can we engage new users to such displays? How can we encourage them to participate or interact with the system? What interaction model is simultaneously appropriate and usable for such users while still enabling useful interaction? How can we resolve conflict situations between multiple, simultaneous users? Further, how can we balance appropriate user feedback while still protecting a user's privacy?

Although researchers have started to investigate such questions within the information domain (e.g. [21][14][11][3]), it is unclear how those ideas translate to the entertainment domain. Based on the growing interest in multi-user gaming, and the increasing deployment of large interactive displays in public spaces, it is clear that understanding how to design meaningful and usable gaming experiences involving these large displays is valuable. In the present work, we discuss the design rationale behind a large interactive public display game called *Polar Defence,* where users interact with the game using SMS messaging through their cell phones. We designed this game based on principles reported in the literature and our own findings in this field [19]. From the deployment of the game in a public space on our university

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campus, we articulate a set of challenges facing designers of similar systems by describing a set of lessons learned from the deployment. Taken together, we found that large interactive public displays hold considerable promise as a platform for shared entertainment.

In the following sections, we derive a conceptualization of "users" within a public space and a user interaction framework based on prior work. We then provide an overview of our game design and development, discussing briefly the deployment of the system. Finally, we articulate a set of lessons gleaned from our deployment, which can guide the design of future game applications for large interactive public displays.

2. "USERS" IN PUBLIC SPACES

In public spaces, there are different types of users (and even non-users) with respect to the display. In this section, we articulate our conceptualization of these types of public display users.

Brignull and Rogers [4], in studying people's activity patterns around similar large display applications, described three classes of users based on their patterns of activity: (i) those engaging in *direct interaction* with the large display; (ii) bystanders whose activities indicated a *focal awareness* of the display, and (iii) bystanders whose activities implied *a peripheral awareness* of the display. To motivate individuals to interact with the system, Brignull and Rogers [4] advocate designing applications to support transitions between these boundaries.

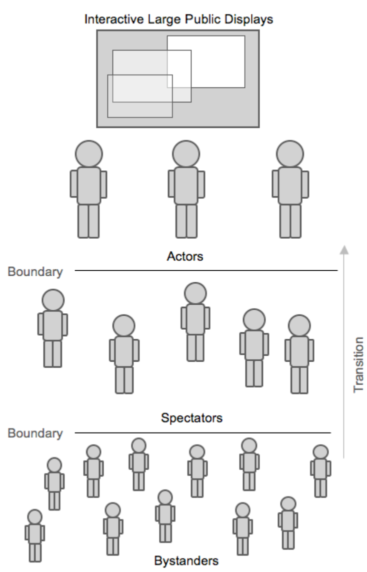

Figure 1: Actors, spectators and bystanders as users in a public space

In our early research work [19] we found support for this conceptual framework, and showed how our design process called attention to supporting *bystanders' needs* to allow them to more easily transition from a bystander role to a contributor role. This work brought attention to a conceptualization of these "users" in terms of their interactive relationship with the display (similar to [21]). Building on this earlier work ([21][4][19]), figure 1 illustrates three classes of users in public spaces: actors, spectators, and bystanders.

Bystanders are individuals that have no strong interest in the presented content at the display installation. *Spectators* are engaged with the displayed content and surrounding environment, but are not actively manipulating the content on the display. Finally, *actors* feel encouraged by the display environment to take an active role in the content. Actors may control and/or manipulate these displays, e.g. by means of a hand held device and so change the 'flow' and 'pace' of the presented content over time.

Understanding the transitions/boundaries between these user types and exploring various conflict situations (e.g. simultaneous display access) will play a key role in future development of interactive large public display environments. Research has already begun to focus on investigating the issue of boundaries to interaction and how to overcome them (e.g. [4][19][7]).

3. USER INTERACTION FRAMEWORK

With this conceptualization of users, we reinterpreted related work within the context of an organizing framework describing users' interaction state in relation to large public displays. This discussion is an idealized conceptualization, but serves to organize the related literature. Further, it allows us to partition different design problems in relation to the changing motivations of individuals with respect to the large display. This framework consists of seven interrelated states, as shown in figure 2.

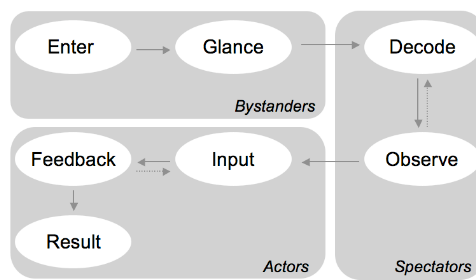

Figure 2: User Interaction Framework

A bystander *enters* a public environment where an interactive display is deployed. Being aware of the installation s/he might *glance* at the display. This brief glance allows the user to decide whether s/he has any interest in the content. If so, s/he may attempt to *decode* the content on the display to better understand what is being presented on the display and the purpose of the installation. In so doing, the bystander becomes a spectator of the display, because s/he is now somewhat engaged with the display. Aside from being a spectator of the display, the user may *observe* other spectators or actors in the environment, who are also engaged with the display. If the user decides to interact with the large display by *inputting* commands or information, s/he becomes an actor. Depending on the interaction model, the user may expect *feedback* to confirm his/her input, which may lead to more user input. This cycle continues until the user has obtained the desired *result*.

This framework organizes related work by showing us when the different design principles from prior researchers are relevant.

3.1 State: *Enter*

Considering the *enter* state reveals the importance of the environment in relation to the display itself. Several authors have argued that the deployment environment itself is a core component of understanding the experience of the system itself (e.g. [19]): First, the location of the display dictates, to some extent, the demographics and the audience who have a chance to see the display. Second, the physical environment can greatly influence ergonomic issues (e.g., ambient lightning, sightlines, color, font size [10]) that affect whether a person will look at the display. Many have recommended pilot testing to ensure that the system has been deployed in a suitable environment and that the visual content is easy for bystanders to perceive (e.g. [19]).

In a recent research study Huang et al. [10] investigated use practices of large ambient (non-interactive) information displays in public settings and recommended positioning displays at near eye-level to encourage glances. In contrast, Brignull & Rogers [4] recommend that designers consider *bodily occlusion* and place displays up higher than peoples' heads. The fact that these authors' design recommendations are in opposition show that while researchers understand the importance of the environment with respect to the display, researchers have yet to come to a common understanding of "ideal" deployment environments.

3.2 State: *Glance*

The *glance* state brings attention to the importance of bystanders' first impressions when they first look at a large display. Many researchers emphasize the importance of this impression in engaging bystanders. Huang et al. [10] report that in their observations of users glancing at public displays, most glances lasted no longer than one or two seconds.

One approach to draw bystanders in is to use interesting content [4]. For instance, Agamanolis [1] suggested using *strange or unusual activity*, which "*makes us glance at a display when we might normally not have*". This approach is used to attract users by relying on curiosity as a major draw. Similarly, Denoue et al. [5] tried to increase user attention using animation on their large display.

3.3 State: *Decode*

When users spend time trying to *decode* the meaning of the display, we consider them to be engaged with display, and call them spectators. Vogel & Balakrishnan [21] argue that the presented content must be comprehensible so that users can easily discover its meaning. According to Tang et al. [19] it is important to make spectators explicitly aware that they *can* actually interact with the display (since this is unusual in most settings). Brignull & Rogers [4] discuss the use of a human assistant around the display to communicate with users around the display. Yet for longer term, or larger scale deployments, this approach may be impractical due to cost issues; thus, we need to discover mechanisms to communicate this "interactive capability" without requiring human intervention.

3.4 State: *Observe*

Considering the *observe* state brings attention to the notion that spectators will begin to observe both the display *and* other users of the display. Reeves et al. [15] discusses the importance of "*designing the spectator's view by revealing interactions.*" They argue actors interacting can attract spectators enabling them to learn how to use the application by watching. Huang et al. [11] suggest similar ideas, suggesting that a "*user's interaction can serve as both instruction and advertising for the system.*"

These ideas accord with Brignull & Rogers [4], who report on the "*honey pot effect*". They observed users (*actors*) interacting with their large display installation using a keyboard as part of their *Opinionizer* application. This attracted other users (*spectators*) to come closer and to communicate with them and so learn how to use the application.

3.5 State: *Input*

The *input* state is the state that describes the user as an actor interacting with large public display following an interaction model. A number of different input modalities have been explored. Vogel & Balakrishnan [21] used simple hand gestures, body orientation and user proximity to interact with their large displays. Based on current technical limitations, real world deployment of such systems might apply only for a small set of dedicated use case scenarios. Alternatively, mobile devices have been found to have many inherent benefits that make it a suitable input device for large screen situated displays (see research survey by Ballagas et al. [2])

Many recommendations have been made on making interactive large public displays easier to use. Paek et al. [14] used mobile devices to interact with a public display Web browser, "*Web Glance*", and recommend that brief user input be used in general because interacting with mobile devices can be cumbersome. In addition, they recommended that applications be able to handle simultaneous user input based on the nature of the multi-user environments. Huang et al. [11] recommend employing mechanisms that have *low use barriers*. Installation and configuration procedures, time-consuming steps in initial use, or functionalities difficult to understand prevent users from using such systems. Brignull & Rogers [4] express the need for the user "*to be able to simply walk up and use it*". They recommend that "*interaction needs to be very lightweight and visible from the outset*".

An important barrier that has been observed in people using interactive large public displays is *social embarrassment* where users fear looking foolish in the eyes of the on-looking audience, especially when they make a mistake shown on the display [4]. Interaction models should therefore consider how to mitigate such barriers. Tang et al. [19] offered both SMS interaction using cell phones and a computer kiosk placed by the display as means to interact with their large screen public application, MAGICBoard. Even though SMS technology has a rather long latency compared to other methods, considerably more users engaged with the display via SMS messaging. Furthermore, SMS users had more time to think about their contribution, and the authors suggested that these users would not experience the same *social embarrassment* [4] as users at the kiosk, who would be exposing themselves to the audience.

3.6 State: *Feedback*

In the *feedback* state, the user receives information from the display based on the interaction thus far. This feedback may be part of the result in which the user is interested, or confirmation that the system has received and is working on the user's input (e.g., like the animated symbol in web browsers indicating that the webpage is being loaded). In this context, Paek et al. [14]

recommend that large public display installations tolerate unpredictable lags in communication. To provide feedback to users, they introduced the notion of providing feedback using a *queue by requests* that shows all user inputs received as well as who will be next. The feedback state is especially necessary when simultaneous inputs are received but the application can only process/present them in a sequential order.

3.7 State: *Result*

The *result* state is the state when the system displays the final output of the series of user interactions. Most of the interactive large display installations we surveyed were designed in a way that presented results not only for the actual *actor* but also the greater audience, again attracting *spectators* and *bystanders* to get involved. The *MAGIGBoard* by Tang et al. [19] and *Dynamo* by Brignull et al. [3] show examples of how to design an interface showing results on a large public display. A different approach is used by the *Manhattan Mashup* project in which result elements were presented on the user's mobile device, as well as large public displays [20].

4. GAME DESIGN/DEVELOPMENT

In the following section, we will present the design and development of *Polar Defence*, a game designed for interactive large public displays. Our design is based on the conceptualization of users in public spaces and the associated design principles presented earlier.

4.1 Game concept

The core concept was to design a game for shared entertainment in such a way as to invite a large audience to play in a public space. The installation was designed to be entirely responsible to *engage* the audience, to *inform* how to play, to *confirm* user inputs and to *present* the game play itself. Thus, the experience was intended to be fully self contained, without any human intervention: we dispensed with the notion of having a display "attendant" or "helper" (c.f. [4] [19] [3]), and instead of handing out specialized provisioned devices to interact with the display (e.g. [20]), built mechanisms to allow the public to engage with the display using their own devices. We imposed this constraint to understand the extent our design could attract users without the need for human intervention. Based on well-know technical limitations described in [21], simple gestures were not applicable for our public space. Similarly, we chose not to use kiosk terminals, since they might increase *social embarrassment* [19], thereby inhibiting users from interacting with our public installation.

To engage a larger audience with our game, we decided to use SMS as the means for user input, since it is already widely used and is considered reliable. Allowing users to SMS through their mobile phones also addresses many privacy issues and reduces *social embarrassment* as users can interact with the system anonymously [19]. SMS also provides the system some user identification as it can automatically associate each game player with part of his/her cell phone number. Thus, playing the game does not require the user to log in, which was recommended by [4], [11]. The disadvantage of SMS is its latency, typically several seconds, making it unusable for most game types that require timely user interaction. Many strategy or turn-based games do not require timely user interaction (see [6] for an online example), and we thus saw them as more suitable for SMS-based user input.

The main objective of the *Polar Defence* game is to place towers on a virtual field, which defend the field from oncoming enemies. Enemies traverse the field from left to right and are attacked by projectiles fired from defenders on top of the towers. To play the game, a user sends an SMS message with six coordinates, which specifies the location of each tower on the field. Similar to a chessboard, the field coordinates range from *A to I* and from *1 to 9*. An example SMS text message for the game is "`A3 D4 D5 F6 F9 H1`" (spaces are not considered). The game starts by defender/tower units being placed onto the field. The enemies then walk across the field and the defenders automatically try shooting them down, both according to predefined algorithms, and no further user input is required.

4.2 Design

Our general user interface design separated our display installation into an *information display* and a *game display*. The *information display* provided visual elements to engage bystanders at the Glance state. It further provided information on how to play the game, particularly to spectators in the Decode state. The *game display* confirmed user input as part of the Feedback state (new SMS messages are immediately announced) and showed the game play as part of the Result state.

Figure 3: Sequence of animation to attract the audience

Following guidelines for engagement by [4], [1] and [5] we integrated a large (70% of the information display) eye-catching animation within the information display (see figure 3 for a sequence of the animation). The animation presented the entire game process starting with the user sending a SMS message, towers being placed at coordinates specified by the user, and the game play itself.

The remaining space was reserved for static information: a five-step guide (in text) of how to play, explicit announcements that everybody is allowed to play, the SMS phone number to which to send the coordinates, a notice that no additional charges were required to play beyond the cost of sending a SMS message, and a note that our installation was part of a user study. Static information was designed according to guidelines given by [21], [19].

Figure 4: Information display showing animation and static information about the game

The information display was designed to present everything needed to understand how to play the game, so that the *game display* could be used primarily for game play. The game display interface consists of four static panels.

Figure 5: Game display including game, status, queue and high score panels

(1) The *game* panel, which covered 75% of the entire display, showing the actual game consisting of defenders on top of towers attacking enemies (i.e., the Result state, presented to actors, spectators and bystanders). After placing the towers on this panel, the game took about 40 seconds from start to finish. This provided a reasonable timeframe for spectators and actors to learn the behavior of the enemies and defenders, and so supported learning by watching others play as recommended by [11] and [15]. (2) The *status* panel, which was synchronized with the game panel, identified the current player. The game display revealed part of users' cell phone number, providing a measure of identifiability without compromising the user's identity. To support learning by watching, the input coordinates corresponding to the current game were also displayed, as well as how many enemies were missed and how many were successfully hit so far. (3) A *queue* panel provided feedback as recommended by [14] by showing a queue of all players up next and their game coordinates. (4) The *high score* panel supported the Result state showing the top ten scores along with the associated game players. The high score panel was introduced to this game domain to foster competition among game players as part of the entertainment concept. This is unique from previous interactive display installations that did not have a competitive component: this component encouraged users to repeatedly try improving their score.

Besides the four static panels, the game display also hosted two animated panels with defined time durations. (1) Every time a new game started, an *announcement* panel appeared covering most of the game panel space for about 6 seconds. It signaled that a new game was about to start and presented the user input (i.e., coordinates) to the audience. This panel supported the Feedback state giving the game player confirmation that he or she will be next to play the game. (2) In a similar manner, after a game is finished, the *result* panel covered the game panel for about 6 seconds. The achieved scores were shown to the audience along with the overall standing compared to all previous players. Both panels were designed to be visible from a wide distance in order to draw attention.

Figure 6: Announcement panel and result panel

Both the information display and the game display were developed using Flash 8 and ActionScript 2. In our development process we separated the game logic from the design elements. This enabled us to quickly change the game graphics in a very short time without reprogramming the game logic itself. The Flash code is embedded inside a Web page, which allowed us to literally deploy the game on every display that was connected to the Internet and had a Web browser with a Flash plug-in. Using embedded Flash code allowed us to avoid the hassle of maintaining different code versions or code updates.

The *Polar Defence* game used *RESTBroker* [8] to establish communication between the large screen display and the cell phones. *RESTBroker* is a lightweight middleware that provides abstractions that foster spontaneous interaction with public displays. RESTBroker uses domain specific web protocols based on HTTP and XML to facilitate cross-domain interoperation and enables use by 'in browser' interpreted languages such as Flash and JavaScript.

RESTBroker uses the notion of a named *channel* to allow developers to name individual screens and/or the interactive applications supported by these screens. The backbone of the RESTBroker system is a publish-subscribe event broker that decouples event sources from sinks. Events sent to a channel using HTTP are received by named subscribers registered with one or more channels. In RESTBroker, channels also contain a 'blackboard-like' container for storage of relevant interaction state and content.

The RESTBroker supports SMS, mobile browser and voice interactions "out of the box". A typical deployment of the system is shown in figure 7. Events may be generated from mobile phones from an SMS gateway, Voice XML [22] gateway or mobile browsers directly. They are relayed to subscribers such as the *Polar Defence* game hosting the display, or other servers as shown.

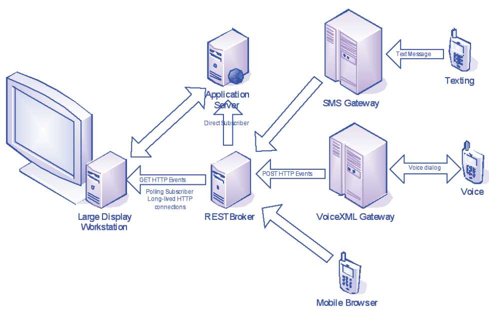

Figure 7: Typical RESTBroker deployment and event flow

In the Polar Defence game we use events to send SMS messages to the game from the SMS gateway, and the RESTBroker state storage to save the game's high scores. The game itself is also stored in a RESTBroker channel for execution by the PC-hosted public display.

5. POLAR DEFENCE IN USE

In order to be able to compare our previous user study [19] with the *Polar Defence* application we deployed the large display game in the same public space at the same location for four days at the main University of British Columbia (UBC) campus. We retained logs of user interaction data. We also observed the public space during the entire study but never made it obvious that we were associated with the display installation nor provided any help to the audience. As part of the observation we recorded the approximate number of people within the space every 10 minutes.

The public space itself consisted of the area around our installation surrounded by chairs and tables, multiple passageways and a popular coffee bar. One major difference in the environment compared to [19] was that the number of chairs and tables had doubled in the interim (~ 40 chairs & 12 tables). In addition, we deployed our game at the end of the student term when students are usually busy preparing for their final exams. To display the information and game display we used two side-by-side projectors that were placed 4m away from the projector wall. The display measured about 6m x 2m and was positioned to be visible from the front door of the building throughout the day. Sound or music was not used as part of the SMS game installation since we didn't want to disturb students studying in this space.

Relaxed atmosphere: The increased number of chairs and tables gave almost everyone who used this public space the chance to sit down, relax, and have a closer look at the large display game without feeling exposed to others. We saw many game players who preferred to sit while playing our game over a longer time period.

Eye Catcher: As hoped our animation drew many people's attention, exceeding our expectations. We frequently saw people glance (*Glance* state) at the installation while they walked by, abruptly stop in their movement, and take time to enjoy the animation (as evidenced by their positive facial expressions). The display surface of the animation itself measured about 2m x 1.80m and was the most visible element of our installation from far away (~30m). The game panel served as a secondary eye catcher, providing good visibility from a closer distance (~15m).

Game instructions: As part of our design concept, we minimized the textual instructions to a short five-step guide, an example of an SMS message, and the phone number to which to send the message (*Decode* state). Even though instructions stated in two different places that a maximum of six towers could be placed in the game, we often overheard people ask: "*So, how many towers can I place on the battlefield?*" We also observed spectators read the instructions and observe the game play, then point out similarities to other online games (e.g., the one reported in [6]).

Learning from others: We frequently observed people instructing others on how to play the game. They seemed to have played our game before and wanted to introduce the rules of the game to their friends. This instruction included pointing at the information display to let the new players know to what phone number to send the SMS message or how to properly format the SMS message.

User dynamics: Players, particularly those in groups, who did well in the game, expressed their success with much emotion, for example, by lifting and waving their arms. Group members communicated a lot with each other while playing the game and exchanged strategies on how to play it and achieve a better score. We often observed spectators start to play the game after spending time observing other groups play. Further, the queue list, used to resolve conflict situations, appeared to be well understood and game players sent SMS messages simultaneously

Advanced game play: At the end of the second day we realized that more and more groups tried to better understand the game in order to get higher scores. They started to make paper notes of the game to figure out the optimal placement of the towers on the field. We recorded many groups trying to refine their strategy and replay the game.

Feedback: As mentioned earlier, each new game started with an *announcement* panel indicating the next player. This seemed to be important to the players since it indicated that s/he "owned" the space for next few seconds. The *result panel* at the end of a game play also seemed to be very important for players, since it gave them and spectators direct feedback on how well they did. This message was much appreciated and triggered emotions, especially for players in groups. Further, the *High Score List* was more than just a feature of an individual game, as it provided long-term feedback for all players, particularly those in the top ten. Group members referred to their place within the High Score List many times while the group played.

Finding new ways of interaction: At the end of the third day and throughout the last day of gaming we received SMS messages from phone numbers starting with +030. These phones numbers were initially unexpected, since cell phone numbers in Canada do not start with +030. We noticed after walking around the public space that some students were using a Web service provided by a local cell network provider enabling them to send free SMS messages over the Internet. In total we got 42 of such SMS messages. Unfortunately, based on the nature of this Web service we could not associate the SMS message with a particular user and so were unable to determine how many individual users played using this service. We saw at least 4 groups, particularly on the last day, use this service.

When we decompose our display installation after the game event was over at the last day of our user study some of the players who had played using the Web service still sat in the public space. We asked the players why they used the service instead of their cell phone. All said that they were on a service plan that charged them for each SMS they sent. Since they liked the game, they looked for ways to play it without paying for it. We asked them if they preferred the Web interface and most said they did not mind using the cell phone except for the SMS charges.

Game results: We received 203 SMS messages over the four days. We received 161 messages directly from cell phones and 42 from the Web service offered by the local network provider. Of all 161 messages received from cell phones, we recorded 57 individual game players. Figure 8 shows that 20 players only played once but the other 37 played at least twice (SMS messages from Web service not included).

SMS messages: Out of the total 203 SMS messages, we found 183 messages without syntax/type errors, and 20 messages with errors, which were corrected by our game logic. Of the 203 received messages in total 193 included coordinates for 6 towers, 5 messages for 5 towers, 1 message for 4 towers and 4 messages for only one tower.

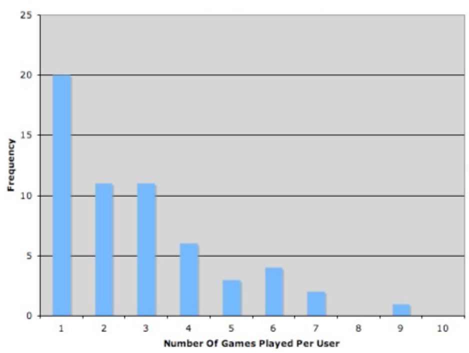

Figure 8: Frequency of games played

6. LESSONS LEARNED

Reflecting on the design and deployment of Polar Defence, we see several design lessons that other researchers can take into their own work.

Support observational learning through simulated users in lieu of real users. Many prior authors have identified the importance of being able to observe other users in helping potential users move past the bystander threshold (e.g. [17][15]). In contrast to many prior large display systems, Polar Defence relies on an interaction technique that is not always easily visible by others. Polar Defence builds on the "mirrored user" approach from Vogel & Balakrishnan [21], and continually loops through a simulated video of interaction showing a simulated user's hand interacting with a mobile phone employing SMS, and showing how that interaction affects the game in a simulated game play scenario. In many ways, this approach is very similar to how video game terminals (in video arcades) use a free play mode to show users the nature of the game: we augment this by also showing how an actual user interacts. In this way, we can support observational learning on a large public display without relying on actual users to make their actions visible to bystanders.

Employ a simple trust model by judiciously communicating system state. Because such systems are not yet part of users' everyday lives, it is important to continually communicate the state of the interaction with the user (as feedback), as well as provide an understanding of the system's privacy model. Users will be uncertain whether they can trust the system: is there an ulterior, disingenuous purpose to this interaction (e.g. will there be a cost to interacting, or will information be otherwise collected)? At an even simpler level, users will be uncertain of how to interact with the display, or whether they can trust the system to function properly. Similarly, users will be uncertain of how (or indeed whether) their privacy will be protected by the system: will their identity be revealed? For this reason, it is important to provide information on or near the display that can allay these uncertainties. We employed a simple model by explicitly branding the display with a research lab's name, and answering many of these simple questions with content on the display itself. Finally, we continually employed feedback about system state to users, both on their mobile devices and on the large display, thereby allaying uncertainties about how their interactions were being interpreted by the system.

Allow users to control how their actions are exposed to bystanders. Similar to the notion of nimbus in CVE or groupware tools [16], it seems to be important to allow users to manipulate the extent to which their interactions are available to others. In public spaces, where a certain protocol or behavior is expected [9], users may not want to behave inappropriately in order to interact with the public display. Polar Defence employs SMS-based input as a covert interaction technique [19], giving users a plausible explanation for their behavior (i.e. using their mobile phone). At the same time, Polar Defence reveals part of the user's cell number, thereby allowing that user to identify themselves as the player of the game (with the game's endorsement) if they so desire. This action is the equivalent of changing one's nimbus. In this way, Polar Defence allows users to selectively decide the extent to which their actions are exposed to others.

Providing features supporting asynchronous competition can drive use of public displays. A continuing challenge with these interactive displays is to drive their use in public spaces. Polar Defence is an example of a display that was able to drive the use by strangers, and we believe strongly that elements of the system that supported asynchronous competition were a key reason for its popularity. Polar Defence employed several simple mechanisms: first, it advertised (though in an obscured way) the identity of the current player, thereby allowing users to see when others were making use of the system; second, it showed the "score" of the user who was currently playing in an obvious manner to bystanders; third, it provided a persistent high score list, allowing users to report their successes to friends or other bystanders. Although it is difficult to demonstrate with concrete evidence, we believe strongly that supporting asynchronous competition of users (even in this simple way) drove up usage of the system; if they had been missing from the deployed game, we expect that we would have seen significantly lower numbers of users.

Many of these lessons, while derived from a simple study of Polar Defence, should be applicable generally toward public display design.

7. CONCLUSION & FUTURE WORK

In this paper, we presented the design, development and deployment of Polar Defence, a game for large interactive public displays. Our game design built upon principles from prior work in the public display and interactive semi-public display domains. The deployment of the game was successful in meeting the challenges described in this research literature. The central contribution of this paper is a reflection on the design and deployment of Polar Defence, where we describe several design lessons that other researchers can consider in their own work. We continue developing and deploying prototype systems for large interactive public displays, which will allow us to validate these findings in other application contexts. For future gaming projects we will focus on interactive multiplayer games supporting direct interaction to increase the level of shared user experiences.

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