GlowPhones: Designing for Proxemics Play with Low-Resolution Displays in Location-based Games

Timothy Merritt[1],Christine Linding Nielsen[2], Frederik Lund Jakobsen[2], Jens Emil Grønbæk[2]
[1]Department of Computer Science, Aalborg University, Aalborg, Denmark
[2]Department of Computer Science, Aarhus University, Aarhus, Denmark
merritt@cs.aau.dk,christinelinding@gmail.com,frederik_lund@hotmail.com,jensemil@cs.au.dk

Figure 1: *Left:* Players navigate to stage locations in the dark forest using light cast from the mobile phone. *Center:* Game stages involve social challenges supported by novel use of smartphone sensors and actuators. Here the player 'mixes' a color by carefully rotating and orienting the screen. *Right:* players complete the final game stage by lighting up sensor panels simultaneously.

ABSTRACT
Location-based mobile games often utilize built-in sensors for supporting game experiences tied to the physical world, yet the visual user interface remains constrained to the small high-resolution screen. GlowPhones is a location-based mobile social game using low-resolution displays to augment the physical space and move the attention away from the mobile screen. Players explore the physical world and collaborate to overcome challenges relying on the screen glow intensity emitted from the phone's screen and light flash frequency of the camera flash for navigation. Three game stages explore proxemics play using low-resolution light displays designed to require social competition, physical cooperation and bodily contact challenging cultural norms. A user study was conducted in a public forest during the night. Spatial analysis of proxemics and F-formations in conjunction with a Game Experience Questionnaire provide insights about the experiential and socio-spatial qualities of low-resolution displays. Qualitative examples offer new strategies for proxemics play.

Author Keywords
Games; proxemics; play; whole-body interaction; mobile social interaction

CHI PLAY '17, October 15-18, 2017, Amsterdam, Netherlands

ACM ISBN 978-1-4503-4898-0/17/10...$ 15.00
DOI: https://doi.org/10.1145/3116595.3116598

ACM Classification Keywords
H5.2 Information interfaces and presentation: User Interfaces.

INTRODUCTION
Location-based games provide experiences orchestrated to respond to the player location as well as actions or situational context [3]. The players are often encouraged to explore and interact with the physical world, yet with intense focus on the small screen of the mobile phone, there are challenges to the richness of social interactions for collocated players and a diminished capacity to attend to stimuli in the physical environment.

We introduce GlowPhones, a mobile social game platform that aims to bring player focus, social interaction and game events out into the physical world using sensors and actuators already in the smartphone. Low-resolution displays are used as a design resource in a mobile social gaming experience to draw attention of the players toward the environment and their co-players. The interactions embedded in the physical world allow for exploring different strategies for proxemics play. In the GlowPhones game, the user navigates to key locations aided by the visual cues provided by changes in the reflected light from the phone into the surroundings. Two low-resolution navigation modes were explored: *screen glow intensity* and *light flash frequency*. In screen glow intensity mode, players must orient the screen toward the ground to activate a navigation mode that uses intensity of glow from the smartphone screen with higher brightness indicating approach to the target geofence. In light flash frequency mode, players orient the camera toward the ground so that cast light illuminates the surroundings and the frequency of camera flash events increases indicating approach to the target geofence. Game stages were designed to explore social play between two people through three different challenges of competitive play, collaborative physical play, and forced collaboration. In the remaining sections we describe the system design, the study conducted "in the wild" of a city forest park at night, and finally we review gathered data from logged game events and feedback from players to provide insights into the player experience. Characteristics of GlowPhones that encourage collaboration and playful proxemic behavior are identified to inspire future development of low-resolution displays for mobile social games. Our discussion of design implications for low-resolution displays suggest new strategies for supporting social interaction as well as involving proxemics play in mobile social games.

RELATED WORK

Low-Resolution and Rich Communication

Previous work on limited and minimal communication tools suggest that 'richness' in communication media should not entirely focus on bandwidth and accuracy of interpretation [41] but rather should focus on the social interactions of people and 'suggestive' communication, embracing ambiguity [9], and aesthetics of the bodily experience [38]. Low bandwidth communication, even down to one-bit communication channels can be used for rich human communication [19]. Pousman and Stasko provided an analysis of the design space for ambient information systems that provides a language for discussing the formal qualities of displays [39]. They present four design dimensions including information capacity, notification level, representational fidelity, and aesthetic emphasis to describe and discuss existing systems and implications for future design opportunities. 'Information capacity was described as the number of data elements that are represented, with high information capacity possible with full resolution screens, while low information capacity systems convey fewer data elements as in the Ambient Orb [7] which uses simple glow levels and subtle color change events to encode information. Display technologies with low information capacity have been explored for use in various contexts including auditory mediation [5], low-resolution visual displays [42] [1], and even low resolution haptic cues to provide navigation and directional guidance [46]. We use the term, "low-resolution displays" as a general term which recognizes the low information capacity of a media yet is independent of the representational fidelity.

Robinson et al. argue for thinking beyond the high-resolution screen of the small mobile device in the design of rich user experiences [44]. They discuss examples of designing ambient media to shift focus into the physical world as in the "Babbage Cabbage technique" of engineering plants to change color as a means of embedding digitally controlled information into the environment [8]. Various other forms of ambient living media have been proposed [4] including glowing bacteria in peripheral display system that provides a low bandwidth of information regarding social media and interpersonal relationships. In that work, the authors recognize that high bandwidth displays of the mobile and personal computer may not be the most effective way to make an impression on the user. Harrison et al. explore the expressive capabilities of 'point lights' or single pixel light sources which are often found on electronic devices and appliances drawing attention to the richness of single pixel displays [13].

There are also examples of physical and social games using low resolution screens to bring the visible game elements into the physical space [22]. Low resolution does not diminish the usefulness of a display - on the contrary, when less information is provided, attention can be more focused on a task. Research on low resolution wearable displays for traffic safety demonstrated that low resolution can yield highly visible indicators for interactions in public [40]. While many mobile experiences are designed for daytime use, when the sun has set, we experience light and changes in the environment more clearly [28]. Interaction in the dark reduces the overall visual feedback and leads people to be more aware of their body and the surrounding space [51]. We noticed that the light given off by the mobile phone screen and the camera flash can be extremely bright, especially in a dark environment.

Social Interaction and Spatial Behavior

The interplay between bodies and space and its effects on social experiences have been widely explored within the research field of interaction design for the medical context [47], social play and mobile games [14, 15]. In this endeavor, research from social psychology has shown to be instrumental. The study of proxemics [12] accounts for how people use features in the environment as ways of structuring their social relationships. It further suggests that personal expectations and cultural attitudes impact the behavior in social encounters as much as the built environment. These ideas have been extended to interaction design in understanding the spatial relationships between people and technology [11, 30, 36, 24, 29]. Krogh et al. argue that a literacy in proxemics (i.e., a socio-spatial literacy) can be used as a design resource for actively designing spatial interventions that have impact on the experienced social space [24]. Furthermore, the F-formation system [20] has been proposed for categorizing people's facing formations with a set of spatial patterns. The o-space of an F-formation describes the shared physical space in front of the people facing each other, whereas the transactional segment denotes the immediate visual space in front a single person [20]. This language for spatial behavior has been adopted in HCI to provide implications for interaction design [30, 36, 29, 48]. New F-formations have been identified from a study of people cooking together, e.g. *spooning* as an intimate enactment of social cooking [36].

Physical, Social, and Location-Based Games

Within games research, the *magic circle* [45] is commonly described as a metaphorical circle within the game experience where special rules apply [18]. We recognize that in designing a game experience, users can be willing to have fun engaging in activities and following rules, while suspending disbelief and engaging in the narrative of the game world.

[1] Jim Campbell portfolio `http://www.jimcampbell.tv/portfolio/low_resolution_works/`

Using physical space as game elements in social games has been explored to enhance social engagement, e.g., through Mueller et al.'s concept of Proxemics Play [32]. The concept extends the traditional proxemic zones using wireless technologies to challenge cultural norms and facilitate exploration of proxemic zones through play. The use of proximity sensors in social play has further been used to encourage social interaction between people in public streets [35] and as a means for supporting exploratory educational experiences [23] and mixed reality entertainment for the family [21].

Location-based or locative media explores tagging and mapping of the real world, assigning content and interactions to spaces, places, people or things [49]. Tagging is either done with virtual tagging of the world or by tracing the action of subjects in the world. It is concerned with lived place and historical surface creating a geospatial experience and can make us reflect on our spatial and social selves [6]. When designing location-based games, the creation and orchestration of game content and activities is key to a successful game experience. Geocaching is a commonly utilized game mechanic embedding goals within the game into real-world physical caches pursued and found by the players [34, 48]. Pokémon Go [1] provides an Augmented Reality realization of fictional characters placed at specific locations in the physical world however, social interaction is minimal. Current mobile phones have powerful built-in sensors that can support unique gaming experiences that bring the focus beyond the small individual screen and back to the physical and social interactions [17, 27, 43, 16].

RESEARCH PROBLEM

We are intrigued by low bandwidth, low-resolution displays as a design resource in a mobile social gaming experience, specifically in the capacity to draw attention of the players toward the environment and their co-players. *How can we design enjoyable mobile social game experiences that shift focus away from the high resolution screen of the smartphone and into the physical and social environment?*

GLOWPHONES GAME

GlowPhones is a location-based mobile game that serves as a research platform to explore proxemics play and low-resolution displays. The game play is inspired by orienteering and requires players to navigate to target locations in the real world where they face challenges related to a narrative. Navigation with GlowPhones is provided through the available light sources on a typical smartphone illuminating the area around the player through the brightness of the screen or the frequency of camera flash events. Two players can advance the story by completing three game stages, which present players with social challenges that explore playful proxemic arrangements of players and technology. Built-in smartphone sensors are used to create new spatial experiences for co-players, encouraging them to be creative with their bodies and mobile devices in the surrounding space. The central point of each stage was marked with a physical lantern that would light up and play a sound when completed. We developed the game narrative to fit within the physical environment and incorporates physical features and unique spatial experiences available in the Riis Skov (Riis forest) [50] city park including a monumental building, a bridge over a stream, and a lookout point overlooking the city of Aarhus, Denmark (see Figure 1). The motivation in terms of proxemics is to change the experienced social space in mobile games from players being in private spheres with their individual devices to a shared interactive space using the surroundings for display and interaction. The study investigates how these aspects of interaction fostered intimate and social zones between players, as well as engaging players with the site. The design rationale behind using shared low-resolution light display with limited information and sensors for physical interaction is to make the game an aesthetic and social experience with less emphasis on efficient use, but more on the inherent social qualities of exploration and play [38].

Game Play

The game play of GlowPhones involves three stages. Each stage involves different physical interactions of social play as depicted in Figure 2 between the navigation and challenge stages, which are explained as part of an unfolding narrative. In short, the narrative is a story about a spacecraft that has to be rebuilt in order to launch it. It is presented at various times to the user through screen cards displayed on the mobile screen and based around a fictitious rocket that has crashed in the forest. The players are asked to help fix and relaunch the rocket in order to complete the game (see Figure 2).

Figure 2: The game consists of three stages. A: The players mix chemicals by rotating phone to find color. B: Players jump together to charge the spacecraft battery. C: The players cooperate to light up the panels placed around a tree to launch the space craft. Before each stage there is an initial navigation stage.

Stage 1: Color Match – Competition

The players compete against each other to find specific colors (chemicals) on the screen by rotating the device physically in any direction. When the phone is in motion, the onscreen color is continually modified through palette rotations influenced by the internal orientation sensor (see Figure 2(A)). Fine motor skills are required in order to position the device in precise angles to find the right colors. The first player to find the three colors has successfully mixed the chemicals to build the battery. The stage completion is also signalled by the activation of a lantern hung in a nearby tree (at the center of the geofence).

Stage 2: Jump Together – Physical Collaboration

The target location of the second stage *Jump Together* was on top of a bridge spanning over a creek, approximately 7 meters above the water (see Figure 2(B)). Players are prompted by a screen message to “charge the spacecraft battery” by holding hands and jumping up and down.The phone’s accelerometer detects the motion and an onscreen animation of the battery charge level visualizes their progress. Once the battery is fully charged, a lantern attached to the railing of the bridge is activated signalling stage completion.

Stage 3: Light Up Panels – Forced Cooperation

In the final stage, the players have to physically locate and activate two light sensitive panels, one located on either side of a tree (see Figure 2(C)). In order to stand out among the objects in the forest, four 1cm diameter retroreflective stickers were affixed to the sensor housing. Once the players enter the 25m radius of the geofence, the camera light activates and players are instructed to ignite the rocket by activating the sensors. When the players have located the panels, they have to simultaneously shine light on each of the two panels. When the task is solved, a lantern on the ground next to the tree plays music and activates a play of lights through internally mounted LED strips to indicate that the spacecraft launches and the players have completed the game.

Challenging Proxemics in the Game Stages

From the perspective of proxemics, players relate to each other and their personal zone [12] including their phone. The game challenges proxemic zones in different ways by playing with proxemic barriers. The *"Jump Together"* stage deliberately crosses the barrier between players’ personal zones. The *"Light Up Panels"* stage separates players’ zones with a visual barrier, but players still depend on each other in how they have separate roles for solving the same task (inspired by Goddard et al. [10]). On the other hand, the *"Color Match"* stage is competitive and players are in close proximity allowing for awareness of their co-player’s game state through peeking at the screen.

Navigation Methods

The navigation to the stations was provided with two strategies for light-based navigation including *light flash frequency* (see Figure 3), similar to Harrison et al. ‘blink decreasing’ and ‘blink increasing’ light behaviors [13] an *screen glow intensity* (see Figure 4), similar to what Harrison et al. called ‘staircase continuous’ light behavior [13]. The methods display the straight-line distance to the stations through modulating the light emitted from the mobile. To supplement the light-based navigation and avoid wild detours in the forest, the narrative supplies initial cues to help guide the players toward the stations making reference to environmental details such as ‘...the station is found toward the water.’

Light flash frequency utilizes the camera flash bulb but does not take a photo. It serves to light up the surroundings for a brief moment and through the strobe frequency it is used to provide proximity feedback. This navigation method is implemented with ten levels comparing the distance and setting the strobe light intensity from 1 flash per 10 seconds at a distance greater than 400m increasing up to 5 flashes per second at the geofence. *Screen glow intensity* is controlled by varying the size of white circle on a black screen that expands when the user approaches the geofence. The circle size is inversely mapped to the distance to the geofence, making the circle grow in small steps upon approaching the geofence thus emitting more light and providing a noticeable increase in glow level. We mapped the area surrounding the circle to blink red if the newest GPS registered location is further away or green if the player is getting closer. We utilized the orientation sensor in the mobile phone to enforce a rule that the player must orient the screen toward the ground so that they can only see the back of the phone when looking down on it carried in their hand. If the phone is turned over in the hopes of peeking at the screen, the screen turns off until the player returns the phone to the screen-down position. This design consideration is among the more significant choices in GlowPhones. It imposes an unconventional way of holding a mobile device, however, it resonates with the proxemics motivation of turning the surroundings, rather than the device screen, into an interactive space.

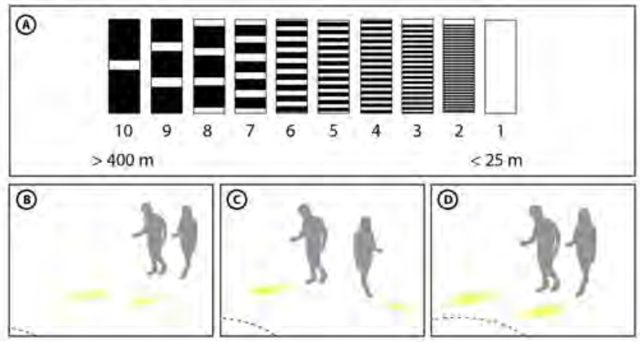

Figure 3: **Light flash frequency navigation.** A: Flashing frequency varies from 1 flash per 10 seconds at a distance greater than 400m increasing to 5 flashes per second at the geofence. B-D: Flash frequency increases as the player approaches the geofence (marked with a dashed line). C: The player closest to the geofence has more frequent light flashes than the player on the right.

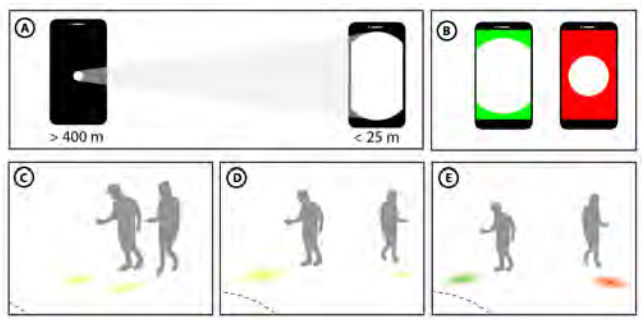

Figure 4: **Screen glow intensity navigation.** A: The white circle grows in size linearly as the player approaches the geofence. B+E: A green border indicates ‘approaching geofence’, red indicates ‘retreating from geofence’. C-D: The glowing circle is biggest thus casting more light for the person closest to the geofence.

TECHNICAL IMPLEMENTATION

The central part of the system is the application that runs on Android devices utilizing built-in sensors for game challenges and navigation. The navigation and challenges run on the devices, but are connected to physical stations in the forest in different ways. Either by sending information of the winner, when the challenge is completed, or receiving information when the station has been activated by a connecting player in the forest. At each station, a lantern is placed, which carries a Particle Photon [37] that offers a connection as a wireless access point to the devices within range and additional components including Neopixel RGB LEDs, an 8 ohm speaker and battery. The challenges are activated when the user's GPS coordinate reaches a geofence (see Figure 5).

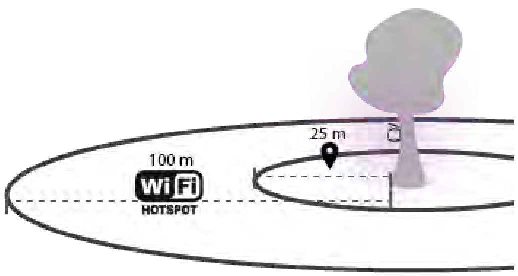

Figure 5: Geofence at game stations. The outer perimeter shows the WiFi range which reaches up to 100m. The inner perimeter is the fixed geofence with bounds at 25m radius around the physical lantern placed on a tree. Placing the geofence well within the WiFi range ensured that phones would join up to the access point well before reaching the target.

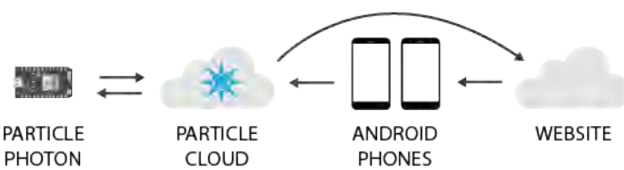

Figure 6: The connections between the phones and the Photons. Stage 1&2 only send data to the Photon, but stage 3 also receives information from cloud through an external website.

The technical implementation of GlowPhones is illustrated in Figure 6. The mobile phones send messages to the Photons through the Particle Cloud. The code on the Photon then reads the messages and runs the appropriate code. The Particle Cloud supports subscribing to events using webhooks. When Photon code has been executed, an event is sent to an external website, and the phones look for updated information about the last time the code has been executed. Exchanged data allows the connected devices to notify the Particle to light up the lantern when a game has been completed, and react when a physical task is completed.

Evaluation

We utilized the GlowPhones system as an experimental platform to explore low resolution mobile gaming. We conducted a study in the wild and gathered data using the mobile phones and self-reported data using the GEQ (Game Experience Questionnaire) and interviews to explore the game experience relating to game features, navigation modes, and suggestions for improvements. Seven dyads took part in the study, fourteen participants in total with 11 male and 3 females ranging from 22 to 31 years and average of 24.6 years of age and all participants claim to have experience in playing mobile games. The evaluation was conducted over three consecutive days in the darkness of the evening hours ensuring that the public forest park would be dark enough to allow the players to navigate using the light cast from the mobile phones. Before each session, the two participants were shortly briefed with an open-ended interview [25] to establish their general experience with mobile phones. The participants were then introduced to a basic overview of the 2 navigation modes and an indication that the game would involve 3 stages. The two participants were given mobile phones with the GlowPhones game installed. We asked some participants to wear an action camera that would document their play, and study facilitators followed the participants to be available for answering questions during the game play and to observe player behavior. Each session lasted one hour, with approximately 30 minutes for completing the game stages and 30 minutes for answering the questionnaire and interviews. Proxemics [12] and F-formations [20] served as an analytical lens, through which we observed participants. We did not, however, tell participants that we were observing spatial behavior. Based on observations from four facilitators, interesting qualitative examples from the evaluation were observed and analysed in terms of their proxemic configurations of people, technology and physical space. F-formations were used to analyse the social play experience from a spatial perspective, highlighting how players organized themselves during competitive and collaborative play ranging from social to more intimate configurations. In the first stage, the participants navigated using the light flash frequency mode. The facilitators followed the players just within hearing and visual range, in order to observe proxemics, F-formations and communication between the players. In the second stage, the players navigate using the intensity of screen glow. In the third stage, the players were asked to choose the navigation method they would prefer for finding the target location in the final stage “Light Up Panels”. At the completion of the final stage, participants were guided to the vehicle at the starting location and were asked to complete the GEQ. When the questionnaires were completed, contextual interviews were conducted with both players together.

RESULTS

An encouraging result from this study is that all participants understood and utilized the light-based navigation and enjoyed the game experience. We examine the feedback from contextual interviews and GEQ to provide further insights into how the players reacted to the 2 modes of navigation and the 3 game stages. Taken as a whole, the results suggest rich potential in developing mobile social games using low-resolution displays and physical bodily interaction.

Logged Location Data

The route between the stages covered approximately 1 km in a forest area of roughly 0.8 km^2. Collected position data from the mobile phones has been visualized on a heatmap (see Figure 7). The heatmap gives a visual overview of the field and stages. The map shows that the participants tended to stay on the paths, however, some groups took a different route for a short time, but eventually found the way back to the trail with the stage location. Some participants noted that it was part of the enjoyment of the game to temporarily 'get lost' and explore different areas of the forest.

Figure 7: Heatmap of player movements during the game in Riis Skov [50] city park in Aarhus, Denmark. 0) Game starting location, 1) Stage 1, the chemical factory, 2) Stage 2, the power plant 3) Final stage, spacecraft launchpad.

Game Experience Questionnaire

The results of the game experience questionnaire (GEQ) suggest that players had overall a very positive game experience. This is reflected in the high score for positive affect (M = 2.89, SD = 0.74) and the relatively low scores for negative affect (M = 0.75, SD = 0.73) and very low scores for the tension dimension (M = 0.55, SD = 0.68). The high average score for competence (M = 2.27, SD = 1.04) suggests players felt capable of playing the game and comparable to prior studies noted in [33]. Flow (M = 1.74, SD = 0.95) and immersion scores (M = 1.94, SD = 0.33) suggest that players were involved in the game experience to a moderate level. The game was not rated as highly challenging and was an easy game to play (M = 1.11, SD = 0.80) which ensured that all participants could complete the stages and experience each challenge, but future iterations could explore more difficult challenges. Figure 8 shows average gameplay experience scores.

General Responses to Light-based Navigation

The navigation methods had distinct ways of displaying proximity information as seen in figure 3 and 4. Contextual interviews provide additional insights into the player experience with each and overall, the feedback suggests the navigation modes yielded much emphasis on the forest and the surroundings.

> "In relation to the use of the screen to navigate (screen glow), it made me more aware of the forest, because I was forced to look where I walked. The light tells you where to go, that was actually fun" - Participant 14

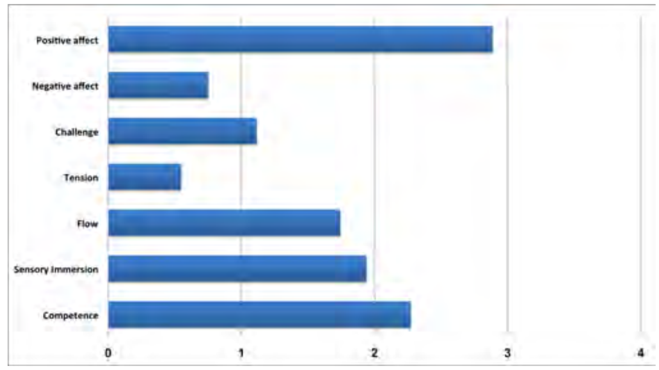

Figure 8: Average gameplay component scores recorded from playing GlowPhones game.

Participants overall preferred navigating with the light flashes over screen glow. Of the 14 participants, 9 preferred the light flashes, whereas 5 preferred the glowing screen. The participants that preferred the glowing screen valued the color change events and understood the glow level and color as a navigation method. One of the advantages of screen glow intensity navigation is the larger bandwidth of information it communicates including the proximity to the geofence and color change events for alerting the player if moving away from the target direction. Additionally, the glowing screen exhibited some unexpected use, which will be elaborated on in the following.

Light Flash Frequency Navigation Method

Generally, the light flashes allowed for a natural upright posture (see Figure 3(B-D)) where players could point the light at the ground right next to each other or pointing outward toward the forest and pathways. Figure 9(A-B) illustrates how the light flash mode allowed for an awareness of the co-player's display. The wide V-shaped formation [36] allows the players to have a peripheral awareness of each other, while primarily facing towards the same reflection on e.g. a tree. This formation was seen used when players were within the geofence (causing their lights to stop flashing and remain on) looking for physical clues of the next task station (see figure 10(right)). Generally, participants found the light flash navigation entertaining but also challenging.

> "I also think the flash was fun because you had to really keep an eye on when it flashed more and there was an extra challenge that you could only see the path ahead in flashes." - Participant 6

Some participants tried to find patterns by counting the seconds between the flashes, and often stopped to look around if the rate changed [Session 1]. Some considered splitting so they could cover a larger area [Session 1, 5]. When participants were walking in a side-by-side formation [20] (see Figure 9(B)), it was apparent that the light flashes were perceived to have a higher frequency because the blinking among devices was not synchronized, yet the cast light overlapped resulting in a perceived increased frequency while the flashes were out of phase [Session 1, 2]. This highlighted a socio-spatial consequence of light reflections, i.e., that a social awareness was enabled by the display being projected out into the players' shared visual space of overlapping transactional segments [20]. Participants also engaged in playful teasing against each other e.g. when players faced each other to use the flashlight for temporarily blinding their co-player [Session 3] (see Figure 9(C)). This shows how simple interfaces can lead to playful social behaviors with players inventing meaning and utilizing the technology for other purposes not intended or specified by the designers as also seen in [19].

Only a few participants chose to use the two navigation modes at the same time, however, in those dyads which did, they seemed to fall into roles. The player using the light flashes walked in front, because of the stronger light source. The participants collaborated and discussed the feedback from the different phones [Session 1].

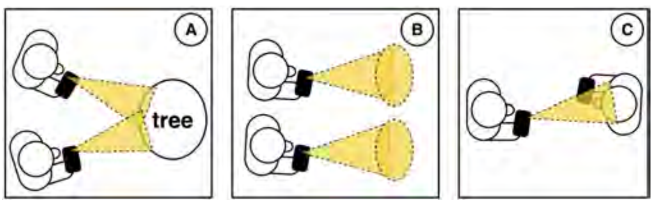

Figure 9: F-formations of players interacting with light in flash frequency mode. A: *Wide V-shaped* - using surroundings to combine reflections. B: *Side-by-side* - interpreting blinking patterns. C: *Face-to-face* - using flash to tease each other in the dark.

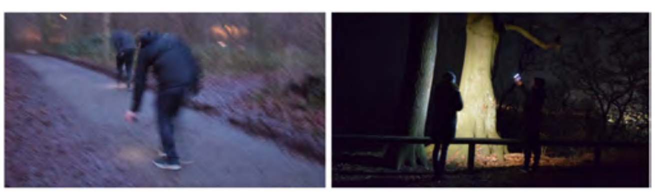

Figure 10: Players' use of surroundings. *Left:* Participants seen crouching down to better see the light emitted from the glowing circle. *Right:* The light reflection as a shared display: The participants often combined the light sources to cooperate locating the light panels placed within the environment.

Screen Glow Intensity Navigation Method

The players understood and could navigate with the light cast on the ground from the screen glow when standing upright with the screen oriented toward the ground. In two sessions, players turned the phone to look at the screen, which causes the screen to turn black and they asked the facilitators why that happens [Session 3, 4]. In some sessions, players appropriated the screen glow in various ways to increase visibility by adjusting their body position, as illustrated in Figure 11. Two players crouched down to move the phone closer to the ground surface as seen in Figure 10, surprisingly few tried to

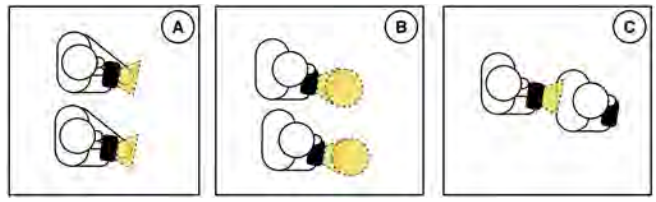

Figure 11: F-formations of players interacting with light in screen glow mode, using tactics to get nearer a reflecting surface. A: *Cupping* with hands, B: *Crouching* closer to the ground, C: *Spooning* by using the back of a participant.

bypass it by holding the phone overhead to peek at the display from underneath [Session 1]. Others were not so satisfied with this method. Due to the short distance to the second location, they were not able to make it work. The changes in glow intensity depends on the distance between the last locations, however some participants walked very slowly and were attending to the color cues. Interestingly, the more intense focus and slow movement actually reduced the usefulness of the cues [Session 1]. One participant felt that the feedback came at random times, and would like to be able to activate it themselves [Session 5]. The feedback colors were sometimes wrong, causing a dyad to count three samples: two red and one green, and then concluded it was the wrong direction because there was more red blinks than green [Session 6].

Because of the unusual angle of the phone, the participants adapted various unexpected spatial configurations for better interpreting the low-resolution output. These examples reveal particular social behavior in how they mimic each others' spatial behavior. Two players held their hand a few centimeters below the glowing screen, shortening the distance to the reflection claiming in the interview that this helped them see the color.

Similarly, two players crouched down to hover the phone over the ground surface (see Figure 11(B) and Figure 10(left)). [Session 1]. In one session, players complemented each other, when one player used the other player's back to better discern the changes in the information given from the screen glow (see Figure 11(C)) [Session 5]. These examples illustrate how nontraditional interaction with the mobile display can cause creative social use of technology.

Social Interactions During Game Tasks

The tasks in the three game stages were designed to explore different social interactions: the *Color Match* game was a competitive task, *Jump Together* involved physical collaboration, and *Light Up Panels* enforced verbal collaboration in a collective task. During the tasks at the three stages, the limited information and vague cues from the narrative served the purpose of encouraging collaborative sense making. Especially in stage 3, as players were locating light sensors, they discussed what the cues meant while simultaneously exploring the physical surroundings near the tree in stage 3. Furthermore, dialogue between the two players suggest that the complexity of the task and the mapping between digital and physical information made them pay extra attention to the surroundings during this task.

Players found the *Jump Together* task quite funny and did not hesitate to engage in the challenge. This suggests that even simple prompts by the game can invite and lead players to cross cultural barriers for bodily contact. While not so surprising for the players who were a romantic couple to hold hands, we discussed this topic further with all participants revealing additional details that contributed to the willingness for hand holding. As noted by Participant 2,

> "The jumping game was fun, because it took me by surprise, also with the fact that the screen was filled out [battery metaphor] was quite different so it made it fun."

Some players reflected in the contextual interview that it would be easy to hack the system by merely shaking the phone, yet when they were asked why they went along with holding hands, it became apparent that hacking the system didn't come to mind until after the game [Session 3, 6].

Physical Lanterns and Disturbed Night Vision

The lanterns were intended as a simple reward to indicate progression in the game – sharp chirping sounds came from the lantern to raise the awareness. However, few participants paid attention to the lanterns. Before *Color Match*, most participants discovered the lantern from the subtle default light emitted, but only very few noticed the lantern light up upon stage completion. The feedback from the interviews suggests that it was not easily noticed among the brightness of the mobile phones; this night blindness can be a challenge as noted in other work [26]. During *Jump Together* none of the participants were aware of the lantern light up. However, at the *Light Up Panels* task all participants discovered the lantern light upon stage completion. The retro-reflective dots on the light panels captured the attention of most players when their camera flashlights illuminated it from a distance.

CHALLENGING THE PERSONAL MOBILE DISPLAY

The main design goal of GlowPhones was to move user attention away from the mobile display by utilizing low-resolution output that would encourage users to attend more to the environment and surroundings. The following discusses design qualities and challenges of designing 'away from the mobile display'.

From Personal to Shared Navigation

A few design decisions in the navigation design took part in nudging the user to attend to the physical surroundings by intervening with traditional use of smartphones. 1) The game is location-based, and the game is designed for a night-time experience re-purposing the phone as a "smart torch" with location awareness information. 2) Site-specific cues in the narrative that built on the players' common knowledge of the site. 3) Light from the phone projecting onto the real world is used for navigation and is visible to both players and spectators. When using the screen glow intensity for navigation, players were forced to orient their phone's screen downward and away from their eyes in order to activate the navigational guidance. Making the simple intervention of nudging users to point their display to the environment and relying on the information reflected from the surfaces around them (e.g., the ground or the trees) changes the mobile display from a private to a shared peripheral display as seen in Figure 10. This could be seen in how they had shared access to the patterns of light being reflected in the environment from each phone, or how they used each other in the interaction, as described with Figures 9 and 11. These examples can be contrasted to the proxemic behavior usually unfolding when two people have the device information facing towards themselves, such as the screen-focused interaction in Pokémon Go. Thus, a shared experience can be designed for by intentionally intervening with the traditional spatial configurations of technology and users.

Transitioning between Mobile and Spatial Display

It is especially challenging to design transitions between interaction with the mobile screen and the lanterns in the physical surrounding space. If a sound or light event emanates from the mobile, the player will likely look at it. Comparing how the participants reacted to the different stages reveals how some design aspects make participants more attentive to the environment than others. In stage 3, most players clearly understood that they finished their task just from the ambient information and the glowing lantern in the tree. While this worked well in stage 3, the design of stages 1 and 2 seemed to compete more with the attention required towards the phone. Especially in stage 1, when players try to find a color by rotating the screen, the mobile screen captured the participants' attention more and only one group discovered the lantern in the nearby tree. They either did not notice it or were blinded by the light emitted from their phones. During the user studies, the brightness of the screens were adjusted to a minimum, however, the participants still reported being blinded by the screen light when consecutively having to refocus on the environment. This points towards a more general challenge for using light-based communication in a night game in the forest. 8 ohm speakers were embedded in the lanterns, however, in stage 1 and 2 the sound events did not seem to be loud enough to compete with the attention toward the screens or the task. In future iterations of the game, sound could be further explored as a low-resolution modality in combination with light flashing away from the user's eye to make information in the surroundings more discoverable in low-light conditions.

AESTHETICS OF LIMITED INFORMATION

The playful interactions in GlowPhones highlights the potential of aesthetic interaction [38] and further the value of the body in the physical world in combination with virtual elements to drive a social game experience [10, 23]. The following discusses social and aesthetic qualities of limited information.

Designing Aesthetic Navigation

One of the inherent qualities of using low-resolution displays is that it provides users with ambiguous or incomplete information, affording users to interpret, try to make sense of it, or encouraging the player to look for other pieces of contextual information to supplement. While this might seem like an odd choice in a navigation system given that it would be less efficient than e.g. Google Maps, it provides guidance through more aesthetic and playful qualities [52] that can be desirable in a gaming experience. The two navigation methods used in GlowPhones do not aim at increasing the efficiency for using navigation, but rather to encourage social interaction and persuade users to look elsewhere for cues to their navigation. This can be compared to being a "puzzle" that the players need to overcome. The navigation methods used in GlowPhones give ambiguous and complex information to the players, who need to interpret the cues to determine where to move in order to approach the target location.

Limited Information Allows for Human Communication

The GlowPhones navigation design allows for the user to have a higher awareness of the surrounding forest. This quality has some similarities to the puzzle solving used in Geocaching games [34]. It potentially gives the players a higher engagement with the game play, other players, and the surroundings. The users were able to find the selected locations through triangulation of the data provided from the game. Throughout the game, the players engaged with informational prompts and onscreen content including the narrative, stage challenges, and ambient light-based navigation methods. Furthermore, the paths in the physical environment were, for most players, as important as the digital information. If there was a path in the direction that seemed to increase intensity in the light, players assumed it was an indication that they were on the right track. While it is challenging to design transitions in user attention between the phone screen and the physical surroundings, mixing digital and physical elements can create complexity. Our study shows that seeking contextual information beyond the low-resolution display is encouraged by its limited information. Furthermore, the relationship between information encourages interpretation, and this has shown to encourage engagement with the system and other users [9, 10]. Gaver et al. thus suggest to deliberately use ambiguity to give rise to uncertainty and encourage discussion. The imprecision of the navigation methods in GlowPhones seemed to encourage much verbal communication between the two players about how to interpret the signals. Kaye et al.'s minimal intimate object [19] reveals how low-resolution displays can offer new means for remote intimate communication. In cooperative gameplay for separated players, small movements and actions can lead to interpretation and mentalizing of co-players to understand intentions [31]. Since GlowPhones is a collocated interactive experience with similar low-resolution elements, it offers an example of what material aspects of low resolution mean for proxemics and collocated collaboration. Our observations indicate that the complexity of the navigation task combined with limited information encouraged verbal communication about where to go or how to interpret the flashes from the phones. This suggests that moving the complexity away from the mobile screens encourages collaboration. And it further illustrates how the limited information allows for the communication to extend into the interpersonal communication between players during interaction and game play.

PROXEMICS PLAY WITH LOW-RESOLUTION DISPLAYS

This section discusses the experiential qualities of low-resolution displays in social games from the perspective of proxemics. The low-resolution design of GlowPhones provides a good case for illustrating how design features of technology have the potential in persuading certain spatial behavior of users and hence influence the social experience in a collocated social game. The following identifies key spatial features in low-resolution displays that suggest new strategic elements in designing for proxemics play.

Dimmed Light Causes Creative F-formations

Experimenting with different light sources from the mobile phone led to important findings regarding properties of low-resolution displays. Harrison et al. suggests that expanding light displays with varying color, size, directionality, diffuseness, and shape would enhance the expressive capability of light displays, however, increasing the complexity. [13]. Our study further explores these physical phenomena and their socio-spatial significance and meaning in a gaming experience. A key design decision was to detect the *directionality* of the device (screen glow navigation) to force the screen to face downwards. Through experiments it became clear that people's traditional use of mobile phones is competing with this interaction concept. Traditional use in mobile games is to face the screen of the phone towards the player where they need to focus.

The short range of light with screen glow navigation exhibited surprising playful bodily configurations of players and technology. Analysing players' spatial behavior, some of the F-formations were reminiscent of those in related work. In Figure 11(A-B) both participants cupped the light or crouched, whereas in Figure 11(C), one player used the back of the other to be able to see higher intensity light from the reflection of screen light. The latter is reminiscent of the *spooning* pattern – identified in Paay et al.'s study of people cooking together [36] – which exhibits a particular intimate enactment between the participants. What is to be noted here is that spatial properties of the actuation (e.g., light) takes part in shaping the social experience, suggesting a new area to explore for proxemics play. While the Kaye et al.'s minimal intimate objects [19] offered new means for remote intimate communication using low resolution, our study illustrates how low-resolution displays serve as collocated intimate communication objects through their spatial consequences, e.g. the glowing screen's short distance resulted in dyads using a spooning formation.

Playing with Proxemic Barriers

An important argument from our study is that it provides an example of how simple design strategies can play with proxemic zones of players in the game. Related work on proxemics play provide strategies for how wireless technologies can make people cross cultural barriers. In the examples of Musical Embrace and Jelly-Stomp [32], players are enticed to lower the distance between each other by exploiting physical properties of sensors (e.g. sensing pressure/touch or breaking Bluetooth reception), potentially causing physical contact between strangers. Observations of the *Jump Together* game complements [32] in suggesting that proxemics play can be

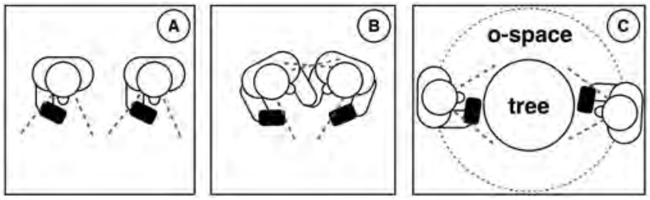

Figure 12: Transactional segments of players in the three game stages creating proxemic zones. A: *Cocoon* - Players' segments were constrained by the attention from bright screens. B: *Hand holding* - Players crossed personal zones to solve task. C: *Separation* - Players' o-space is separated by a tree.

designed for in very simple game modifications. In our case, the distance between players is deliberately lowered by encouraging touch through the narrative. A particular design goal in the *Jump Together* stage was to design for proxemics play by crossing cultural barriers. Deliberate use of hand holding for completing a task (see Figure 12(B)) encouraged the participants to engage on a social level that would otherwise be uncommon in everyday life. Surprisingly every pair of participants engaged in this activity without trying to cheat the system, even though it was occasionally followed by a comment that the hand holding could not be detected by the system (i.e., no sensor enforces hand holding). This suggests, as articulated in [10] that the "magic circle" of the game world extends beyond the sensors and actuators of the mobile device and into the social behaviors and reactions when the game calls for engaging people in activities that challenge cultural norms and expectations.

Furthermore, we extend this idea of playing with proxemic barriers by deliberately creating barriers between players. Goddard et al. use the example of the mobile game Spaceteam [2] in how it necessitates collaboration through verbal communication between players by the asymmetry in the design [10]. The players have, as reported in that work, complementary roles in that their individual interfaces contain different information that the others might be dependent on. As opposed to screen sharing, players are forced to constantly keep an eye on their individual screens, while verbally communicating crucial information to one's collaborators. Similarly in GlowPhones, the designed spatial configuration in the *Light Up Panels* task consisted of light sensors strategically placed on opposite sides of the tree to create an intentional visual barrier between the participants. In the F-formation depicted in Figure 12(C), the tree acts as a barrier between the participants' transactional segments right in their o-space [20], forcing them out of a traditional social space (i.e., [12]) with face-to-face contact, into a spatial configuration where they were physically separated. The task to solve the puzzle of the stage involved a tightly-coupled collaboration between the two participants, where they had to synchronously light up the panels. This encouraged them to verbalize their actions in order to succeed. Hence, inspired by Spaceteam, the design of *Light Up Panels* illustrates how restricting visual access to shared resources (i.e., deviating from traditional physical means of communication) through an unconventional F-formation with a physical barrier can increase verbal communication. Furthermore, both examples of playing with proxemic barriers in interaction design illustrate very simple strategies and game modifications for engaging proxemics in play. We hope this encourages designers to look into even simpler design strategies than those proposed by Mueller at al. [32].

Light as Awareness of Zones

Mueller et al. discuss the potential of interaction design in making people discover wireless and proxemics zones [32]. GlowPhones extends this strategy with an analytical focus on light as a medium for creating zones. The *Color Match* task provides an illustration for comparison with the other two tasks in relation to proxemic zones. *Color Match* requires no collaboration between the participants, and thus in comparison, the proxemic zones are separated, given that the participants neither interact through the task, nor through physical closeness. Being collocated they had a peripheral awareness of the other's screen, however, users were often observed to be concentrated on their private displays, indicated by the fact that no one noticed the lantern lighting up when one completed the task. As mentioned in statements from participants, they were aware how the blinding from a bright screen limited their ability to attend to the surroundings. In this way, the light source highlights where the attention is during *Color Match* and creates a 'cocoon' zone around each individual player with a screen (see Figure 12(A)) that constrains their awareness to the surroundings. Similar to this argument, the light flashes and lanterns act as indicators of zones, making the zones more visible. The blurry and invisible zone of the Wifi range around the task stations were made visible when the lanterns lit up from interactions on the phone. Furthermore, the geofence was made tangible with the light flashes that changed from a blinking pattern to constant light. Along those lines, the observed F-formations around the navigation interactions (see Figure 9 and 11) illustrate how they would actively engage with each others' personal zones using the cones projecting from the light sources. The results from this study indicate a potential in using light as an ambient interface for awareness of wireless and proxemic zones [32].

CONCLUSION

We presented GlowPhones, a location-based mobile game that brings play into the physical world utilizing low-resolution light-based navigation and site-specific challenges. In this work, we demonstrate how low-resolution displays can turn mobile devices from private into shared displays that encourage users to look away from their devices and engage with the surrounding site. Limited information encourages users to collaborate and look for information in the physical world. Low-resolution displays have limited bandwidth, yet 'richness' in the medium as shown with GlowPhones comes from aesthetic qualities in how it triggers emotions in the players including piqued curiosity and stimulation of playful proxemic behaviors. We hope this work encourages additional research exploring new areas of proxemics play with low-resolution displays.

REFERENCES

1. Pokémon Go. http://www.pokemongo.com. Accessed: 2016-11-04.
2. Spaceteam. http://spaceteam.ca/. Accessed: 2016-06-04.
3. Benford, S., Anastasi, R., Flintham, M., Drozd, A., Crabtree, A., Greenhalgh, C., Tandavanitj, N., Adams, M., and Farr, J. R. Coping with uncertainty in a Location-Based game. *IEEE Pervasive Computing 2*, 3 (July 2003), 34–41.
4. Cheok, A. D., Kok, R. T., Tan, C., Fernando, O. N. N., Merritt, T., and Sen, J. Y. P. Empathetic living media. In *DIS '08: Proceedings of the 7th ACM conference on Designing interactive systems* (New York, NY, USA, 2008), ACM, pp. 465–473.
5. Chumkamon, S., Tuvaphanthaphiphat, P., and Keeratiwintakorn, P. A blind navigation system using RFID for indoor environments. In *2008 5th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology* (May 2008), vol. 2, IEEE, pp. 765–768.
6. De Lange, M. *Moving circles: Mobile media and playful identities*. 2010.
7. Devices, A. Ambient orb, 2005.
8. Fernando, O. N., Cheok, A. D., Merritt, T., Peiris, R. L., Fernando, C. L., Ranasinghe, N., Wickrama, I., and Karunanayaka, K. Babbage cabbage: Biological empathetic media. In *VRIC Laval Virtual Proceedings* (Apr. 2009), pp. 363–366.
9. Gaver, W. W., Beaver, J., and Benford, S. Ambiguity as a resource for design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2003), CHI '03, ACM, pp. 233–240.
10. Goddard, W., Garner, J., and Jensen, M. M. Designing for social play in co-located mobile games. In *Proceedings of the Australasian Computer Science Week Multiconference* (New York, NY, USA, 2016), ACSW '16, ACM, pp. 68:1–68:10.
11. Greenberg, S., Marquardt, N., Ballendat, T., Diaz-Marino, R., and Wang, M. Proxemic interactions: the new ubicomp? *interactions 18*, 1 (2011), 42–50.
12. Hall, E. T. *The Hidden Dimension*. 1966.
13. Harrison, C., Horstman, J., Hsieh, G., and Hudson, S. Unlocking the expressivity of point lights. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2012), CHI '12, ACM, pp. 1683–1692.
14. Isbister, K. Connecting through play. *interactions 23*, 4 (June 2016), 26–33.
15. Isbister, K., Abe, K., and Karlesky, M. Interdependent wearables (for play): A strong concept for design. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2017), CHI '17, ACM, pp. 465–471.
16. Isbister, K., Márquez Segura, E., Kirkpatrick, S., Chen, X., Salahuddin, S., Cao, G., and Tang, R. Yamove! a movement synchrony game that choreographs social interaction. *Human Technology 12* (2016), 74–102.
17. Joselli, M., and Clua, E. gRmobile: A framework for touch and accelerometer gesture recognition for mobile games. In *2009 VIII Brazilian Symposium on Games and Digital Entertainment* (2009), IEEE, pp. 141–150.
18. Juul, J. The magic circle and the puzzle piece. In *Conference proceedings of the philosophy of computer games* (2008), vol. 56.
19. Kaye, J. ., Levitt, M. K., Nevins, J., Golden, J., and Schmidt, V. Communicating intimacy one bit at a time. In *CHI '05: CHI '05 extended abstracts on Human factors in computing systems* (New York, NY, USA, 2005), ACM, pp. 1529–1532.
20. Kendon, A. Spatial organization in social encounters: The f-formation system. *Conducting interaction: Patterns of behavior in focused encounters* (1990), 209–238.
21. Khoo, E., Merritt, T., and Cheok, A. Designing a mixed reality intergenerational entertainment system. In *The Engineering of Mixed Reality Systems*, E. Dubois, P. Gray, and L. Nigay, Eds., Human-Computer Interaction Series. Springer London, London, 2010, ch. 7, pp. 121–141.
22. Khoo, E. T., Merritt, T., and Cheok, A. D. Designing physical and social intergenerational family entertainment. *Interacting with Computers 21*, 1-2 (Jan. 2009), 76–87.
23. Khoo, E. T., Merritt, T., Fei, V. L., Liu, W., Rahaman, H., Prasad, J., and Marsh, T. Body music: physical exploration of music theory. In *Sandbox '08: Proceedings of the 2008 ACM SIGGRAPH symposium on Video games* (New York, NY, USA, 2008), ACM, pp. 35–42.
24. Krogh, P. G., Petersen, M. G., O'Hara, K., Grønbæk, J. E., and Rasmussen, M. K. Sensitizing concepts for socio-spatial literacy in hci. *Proceedings of Chi'17* (2017).
25. Kvale, S. *Doing interviews*. Sage, 2008.
26. Löchtefeld, M., Lautemann, N., Gehring, S., and Krüger, A. ambiPad: Enriching mobile digital media with ambient feedback. In *Proceedings of the 16th International Conference on Human-computer Interaction with Mobile Devices & Services* (New York, NY, USA, 2014), MobileHCI '14, ACM, pp. 295–298.

27. LUCERO, A., HOLOPAINEN, J., AND JOKELA, T. Mobicomics: Collaborative use of mobile phones and large displays for public expression. In *Proceedings of the 14th International Conference on Human-computer Interaction with Mobile Devices and Services* (New York, NY, USA, 2012), MobileHCI '12, ACM, pp. 383–392.
28. MARCH, W., NAFUS, D., SWAN, L., AND TAYLOR, A. S. Night and darkness: interaction after dark. In *CHI'08 Extended Abstracts on Human Factors in Computing Systems* (2008), ACM, pp. 3985–3988.
29. MARSHALL, P., ROGERS, Y., AND PANTIDI, N. Using f-formations to analyse spatial patterns of interaction in physical environments. In *Proceedings of the ACM 2011 Conference on Computer Supported Cooperative Work* (New York, NY, USA, 2011), CSCW '11, ACM, pp. 445–454.
30. MENTIS, H. M., O'HARA, K., SELLEN, A., AND TRIVEDI, R. Interaction proxemics and image use in neurosurgery. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12* (New York, New York, USA, 2012), ACM Press, p. 927.
31. MERRITT, T., AND MCGEE, K. Protecting artificial team-mates: More seems like less. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2012), CHI '12, ACM, pp. 2793–2802.
32. MUELLER, F., STELLMACH, S., GREENBERG, S., DIPPON, A., BOLL, S., GARNER, J., KHOT, R., NASEEM, A., AND ALTIMIRA, D. Proxemics play: Understanding proxemics for designing digital play experiences. In *Proceedings of the 2014 Conference on Designing Interactive Systems* (New York, NY, USA, 2014), DIS '14, ACM, pp. 533–542.
33. NACKE, L. E., STELLMACH, S., SASSE, D., AND LINDLEY, C. A. Gameplay experience in a gaze interaction game, Apr. 2010.
34. NEUSTAEDTER, C., TANG, A., AND JUDGE, T. Creating scalable location-based games: lessons from geocaching. *Personal Ubiquitous Comput. 17*, 2 (Feb. 2013), 335–349.
35. PAASOVAARA, S., AND OLSSON, T. Proximity-based automatic exchange of data in mobile gaming: Studying the experiences of streetpass users. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction* (New York, NY, USA, 2016), NordiCHI '16, ACM, pp. 26:1–26:10.
36. PAAY, J., KJELDSKOV, J., SKOV, M. B., AND O'HARA, K. F-formations in cooking together: A digital ethnography using youtube. In *IFIP Conference on Human-Computer Interaction* (2013), Springer, pp. 37–54.
37. PARTICLE INDUSTRIES INC. Particle photon. `https://store.particle.io/`. Accessed: 2017-07-24.
38. PETERSEN, M. G., IVERSEN, O. S., KROGH, P. G., AND LUDVIGSEN, M. Aesthetic interaction: a pragmatist's aesthetics of interactive systems. In *Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques* (2004), ACM, pp. 269–276.
39. POUSMAN, Z., AND STASKO, J. A taxonomy of ambient information systems: Four patterns of design. In *Proceedings of the Working Conference on Advanced Visual Interfaces* (New York, NY, USA, 2006), AVI '06, ACM, pp. 67–74.
40. PUPPENDAHL, T. G., BECHTOLD, O., STRASSEL, L., JAKOB, D., BRAUN, A., AND KUIJPER, A. Enhancing traffic safety with wearable low-resolution displays. In *Proceedings of the 2nd International Workshop on Sensor-based Activity Recognition and Interaction* (New York, NY, USA, 2015), WOAR '15, ACM.
41. RASMUSSEN, M. K., LEHOUX, N., OCNARESCU, I., AND KROGH, P. G. I'Ll knock you when I'M ready...: Reflecting on media richness beyond bandwidth and imitation. In *Proceedings of the Designing Interactive Systems Conference* (New York, NY, USA, 2012), DIS '12, ACM, pp. 106–115.
42. RICHARD GRUSIN, JOHN G. HANHARDT, R. S. J. C. *Jim Campbell: Material Light*. Hatje Cantz, 2010.
43. ROBBINS, H., AND ISBISTER, K. Pixel motion: A surveillance camera-enabled public digital game. In *FDG* (2014).
44. ROBINSON, S., MARSDEN, G., AND JONES, M. *There's Not an App for That: Mobile User Experience Design for Life*, 1 ed. Morgan Kaufmann, Dec. 2014.
45. SALEN, K., AND ZIMMERMAN, E. *Rules of play: Game design fundamentals*. MIT press, 2004.
46. SCHMIDT, A., KLEEMANN, M., MERRITT, T., AND SELKER, T. Tactile communication in extreme contexts: Exploring the design space through kiteboarding. In *Human-Computer Interaction – INTERACT 2015*, J. Abascal, S. Barbosa, M. Fetter, T. Gross, P. Palanque, and M. Winckler, Eds., vol. 9299 of *Lecture Notes in Computer Science*. Springer International Publishing, 2015, pp. 37–54.
47. SONNE, T., MERRITT, T., MARSHALL, P., LOMHOLT, J. J., MÜLLER, J., AND GRØNBÆK, K. Calming children when drawing blood using breath-based biofeedback. In *Proceedings of the 2017 Conference on Designing Interactive Systems* (New York, NY, USA, 2017), DIS '17, ACM, pp. 725–737.
48. TONG, L., SERNA, A., PAGEAUD, S., GEORGE, S., AND TABARD, A. It's not how you stand, it's how you move: F-formations and collaboration dynamics in a mobile learning game. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services* (New York, NY, USA, 2016), MobileHCI '16, ACM, pp. 318–329.

49. TUTERS, M., AND VARNELIS, K. Beyond locative media: Giving shape to the internet of things. *Leonardo 39*, 4 (2006), 357–363.

50. VISITAARHUS. Riis forest. `http://www.visitaarhus.com/ln-int/riis-forest-gdk653297`. Accessed: 2017-07-24.

51. VONGSATHORN, L., O'HARA, K., AND MENTIS, H. M. Bodily interaction in the dark. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2013), ACM, pp. 1275–1278.

52. ZWINDERMAN, M., ZAVIALOVA, T., TETTEROO, D., AND LEHOUCK, P. Oh music, where art thou? In *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services* (New York, NY, USA, 2011), MobileHCI '11, ACM, pp. 533–538.