Flashlight Jigsaw: An Exploratory Study of an Ad-Hoc Multi-Player Game on Public Displays

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ABSTRACT
As large displays become prevalent in public spaces, they could be employed to create novel game experiences for the public. We present an exploratory study of an ad-hoc multi-player game played on such public displays. The game, *Flashlight Jigsaw*, was deployed in a shared lab space and a public atrium for two weeks in total. Through interviews supported by observations and system logs we explored the experiences and behaviors of players and spectators. We also investigated the interrelationship between public display games and the spaces they are deployed in. The research resulted in findings regarding game play, communication, social interaction, spectatorship, and space and location around such a game. We use our findings to develop design implications for future public display games.

Author Keywords
Public display, games, flashlight display, exploratory study.

ACM Classification Keywords
H5.3.Group and organization interfaces: Computer-supported cooperative work. K8.0. Personal computing: Games.

INTRODUCTION
Large-sized displays are increasingly being deployed in public and shared spaces, such as airports, cafes, office lobbies, and classrooms. Such displays allow multiple people to view and potentially interact with displayed data simultaneously. Various applications that leverage these characteristics have been explored, such as accessing public and ambient information [19], supporting information sharing and exchange [8, 11], facilitating group collaboration [10], and encouraging public interaction [4]. As interactive public displays continue to blend into everyday environments, it is likely that they will become a part of an important aspect of daily life in public spaces: play. It is common to see children playing games in city squares, people playing Frisbee in parks, or chess-lovers "duking it out" in bars. These game experiences weave seamlessly into public space usage, and create a lively and social atmosphere for players as well as spectators around. Watching the dynamic between players can sometimes be more fun than actually playing the game itself (e.g., professional sports). The increasing presence of public displays offers a unique opportunity to position computer games as connecting, not isolating, experiences. If we can design highly visible interactive games that invite casual play and spectatorship, they could promote social interaction amongst the public. These games further offer the possibility of improving the quality of public spaces in general through the creation of a shared experience.

Additionally, game applications suffer less from two common challenges that currently hinder casual interactive use of public displays: enticing initial and prolonged users, and privacy concerns. Researchers [4, 6] have reported difficulty in enticing the general public to start interacting with public displays. By framing an application as a light-hearted game, the risks associated with public participation may drop substantially; this makes games a potential "buy-in" application for using other applications on public displays. Another factor that keeps people from using public displays is the concern that private information might be viewed by others, a behavior recorded by Tan and Czerwinski [18]. Several solutions have been proposed to alleviate this problem, such as directing private information to personal devices [7], or letting users wear shutter goggles to filter information owned by others [17], but none completely eliminates the concern. Since games consist of impersonal and publicly available information, they are less likely to raise these privacy concerns. Consequently, games might be a strong candidate application for establishing a beachhead in the public display interaction paradigm.

Despite the potential of public display games, there has been little empirical research into the experiences and behaviors that emerge from game playing on public displays; studies of genuine deployments in pre-existing public spaces are particularly unexplored in the literature. In an effort to explore this space, we present a study of *Flashlight Jigsaw*, a multi-player puzzle game played on a wall-sized public display using wireless handheld controllers, which allows people in public spaces to join and leave the game in an ad-hoc manner. The game was deployed in two locations for a week each: a shared lab space, and a public atrium. We investigated experiences and behaviors from players and spectators, as well as their interactions within the spaces where the game was deployed.

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RELATED WORK

The Notification Collage [8] and the Dynamo [11] systems both supported cooperative sharing of information and media on public displays. Huang et al. [10] explored supporting co-located workgroup interaction on shared displays. Vogel and Balakrishnan [19] investigated how a public display might seamlessly support transitions between ambient, public, and personal interaction. Brignull and Rogers [4] present Opinionizer, a system that encourages socializing between people around the public display.

A variety of input technologies have been used for public displays, including mouse and keyboard [11], direct touch [9], hand gestures [19], and laser pointers [13]. Researchers [7, 12] have also explored using camera-equipped handheld devices such as mobile phones to interact with public displays by direct pointing. With the increasing prevalence of handheld devices, these techniques could make public display interaction more accessible to the general public, and scale to several concurrent users. Other research [2, 5] has also investigated using handheld projectors to create a public display experience on any large surface.

Location-based social games using GPS-enabled mobile devices, which can be played in public spaces and woven into players' personal and public life, have also been investigated [1, 3]. However, these games are played exclusively on mobile devices, hence the game experience is only understood by the players but not surrounding spectators. In particular Bell et al. [3] reported that player behaviors appeared strange to other people around and drew unwanted attention. In contrast, games played on public displays are visible to all people in the space, thus allowing non-players to more readily infer the purpose of the activity.

A few researchers have experimented with games and interactive entertainment using displays in public spaces. Schminky [15] is a multi-player game played on PDAs. The game was deployed in a café for one week, with a public display for showing the social network that resulted from game playing. MobiLenin [16] is an entertainment system that allows people to use mobile phones to vote for music video clips to be played on a public display. It was tested in a 12-minute session in a restaurant, and elicited interesting social behaviors such as co-located grouping and spectatorship. In both systems, the majority of interaction was on the handheld devices and between small groups of people who sat next to each other, rather than with the public display and the larger public. FishPong [21] is a ball-and-paddle style game played on a tabletop display using augmented coffee cups, designed as an "icebreaker" game. Similarly, the form factor of the tabletop display makes it more suited to small groups around the table than the larger public. In comparison, we deliberately designed our interactive game to be played exclusively on a highly-visible public display, which serves as the sole shared focus of attention for all players and spectators in a larger public space. Our system was deployed for 2 weeks, resulting in a larger number of players (both first-time and repeat players), and in more than one location, enabling comparison between types of spaces.

GAME PROTOTYPE

Goals

The question of what constitutes an appropriate game for public displays is a difficult one that is not easily answered without significant real-world usage data, which is currently lacking. To guide our game selection, we considered several goals that a public display game should have:

Casual and lightweight: Most games are designed for dedicated intense play. Games that blend seamlessly into public space experiences must be casual and lightweight enough to be concurrent or multiplexed with other activities, especially social interactions between people.

Simple to understand and operate: Unlike dedicated spaces where people come to play (e.g. casinos, arcades), people typically enter public spaces without forethought of game play, and any participation in games will be ad-hoc. Thus, the game must be simple and quick to understand for both players and spectators without intensive instructions.

Suitable for various populations: Given the usually diverse and dynamic population in public spaces, the game should broadly appeal to people of different ages, educational and ethnic backgrounds, technology experiences, and so on.

Ad-hoc joining and leaving: Similar to some traditional games, the game should allow people to initiate, join or leave at any time in an ad-hoc fashion ("drop in, drop out") without interrupting the game experience.

Encouraging group play and communication: As a part of the social experience in public spaces, the game should not only accommodate but also encourage people playing and communicating in both preformed and spontaneous groups.

Design

We could not find an existing electronic game that satisfied all the above goals. As such, we created a custom game prototype called *Flashlight Jigsaw* which is a multi-player jigsaw puzzle game played on a wall-sized projection display using spatially tracked wireless handheld controllers (Figures 1, 2). We chose jigsaw puzzles because they are familiar to most people and not very intense, but still challenging enough to be interesting. Unlike traditional jigsaws where all pieces are simultaneously visible, pieces in *Flashlight Jigsaw* are only revealed when a virtual "flashlight" cast by handheld controllers illuminates content on a large display (Figure 1a), This is inspired by previous research into handheld projector interaction [5] which could indeed be a viable technology for public interaction once such devices become more technically feasible. Each player can use a button with the crosshair cursor in the center of their flashlight to select and move jigsaw pieces. Rotating the controller about its long axis rotates the selected piece. When a piece has been correctly placed alongside others, they will connect to each other and be moved as a whole.

Each player is assigned a different color as marked on the physical controller, and which also virtually identifies the relevant flashlight and cursor.

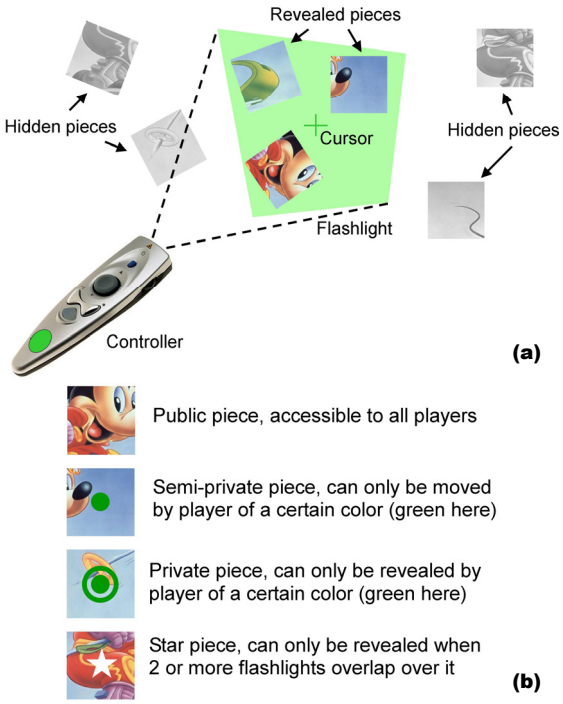

Figure 1. *Flashlight Jigsaw* concept. (a) Flashlight metaphor. (b) Types of jigsaw pieces.

The current prototype has 3 controllers, thus supports up to 3 concurrent players. To elicit interaction between players, each controller has a different viewing and operating power, being able to reveal (with flashlight) or move (with cursor) different jigsaw pieces. Figure 1b illustrates. The type (and associated color if applicable) of each piece is randomly assigned when the puzzle starts. Therefore, players need to work together to discover and fit pieces. When there are fewer than 3 players, a player can switch to another available controller by pressing the "switch" buttons on both controllers, in order to access other pieces. In the case that only one player is present, after the controller switching, all the "star" pieces are converted to pieces of other types, so that a single player can access them.

Players may join or leave the game at any time regardless of the status of the puzzle and other players. Therefore the game seamlessly transitions between different numbers and sets of players. Once a puzzle is completed, another randomly selected puzzle is generated. When there is no one playing, an automatically generated flashlight randomly scans throughout the display to allow passers-by to see the puzzle content, enticing them to play. During play, hint messages appear periodically or when triggered by context, such as reminding players of pieces they cannot access, or suggesting that players find other people to play with.

A player scores points each time s/he places a jigsaw piece correctly. When the entire puzzle is completed, all players present get bonus points, ranging between 50~75% of the puzzle's total score. The player who places the last piece of the puzzle gets the highest bonus. To encourage group play, all scores are multiplied by 1.5 when 2 players are present, and by 2 when 3 players are present. There are no time requirements or incentives. Players can check their records (score, number of puzzles completed, total playing time) by pressing a button on the controller.

Technology

We use a short-throw projector to create a public display measuring roughly 3m x 2m. The game controllers are built from wireless remote presentation controllers with several built-in buttons, and tracked using a Vicon camera-based system (www.vicon.com) providing 6-dof (position + pose) information at millimeter precision. We used the Vicon tracking system to prototype our game with the highest possible quality input. However for wider deployment in in the future, we could consider more accessible technologies like camera-equipped handheld devices [7, 12], which might allow people to use their own devices for interaction.

Given the position and pose of the controllers, and the pre-calibrated geometry of the projection surface, the position, size, and shape of the flashlights are calculated using a mathematical projection model. The game content is then rendered within the flashlight areas accordingly. This results in a realistic-feeling flashlight experience.

DEPLOYMENT STUDY

We deployed *Flashlight Jigsaw* in two locations in an urban university campus, one school week (Mon-Fri) per location.

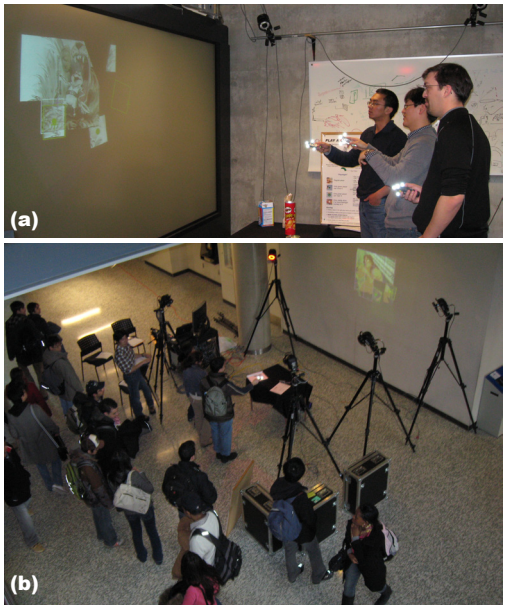

Figure 2. Game deployment spaces. (a) Shared lab space. (b) Public atrium.

In Week 1, the game was deployed in a lab of around 30 computer science graduate students, researchers, and software engineers, who all knew each other previously (Figure 2a). Inside the room there is a wall-sized projection

screen, in front of which is an open space measuring roughly 5m x 3m. Two people work in the room regularly, while others work in adjacent offices. The room also hosts the lab printer, and serves as the passageway between the lab pantry/meeting room and two large shared offices. Thus people frequently pass through the space. The game was available daily between 1-7pm.

In Week 2, the game was deployed in the ground-floor public atrium of a large academic building (Figure 2b). The lower floors consist of classrooms and common areas, resulting in constant traffic throughout the day, especially when classes start or end. Due to the open spaces, public seating, and nearby cafe, people also tend to linger. The probability of people in the atrium knowing each other is much smaller than in the shared lab in Week 1. The display was projected on a wall in an open space of roughly 8m x 5m, which is easily visible throughout the atrium, but not directly in the way of traffic. The game was available daily between 11am-5pm.

We chose these constrasting locations to investigate how people reacted to the presence of the game in both a shared space with a relatively fixed set of occupants, and a public space with a more diverse and transient population. In both locations, a poster illustrated the concepts of the game. Flyers with the same content were available for pick up. When appropriate, the onsite game facilitator would encourage people who stopped at the game installation to play. An online blog kept updated player rankings and allowed people to leave game-related comments.

Fifty different puzzles were used in the deployments, all generated from pictures of Disney cartoons, chosen for their popularity and familiarity in North American culture. Each puzzle was segmented into 10-20 pieces.

To offer continuity of experience and personal identity to the players, as well as for the ease of organizing and analyzing the study data, each player is assigned a unique ID by the game facilitator when the player plays for the first time. The game facilitator is responsible for logging in/out the player to a specific controller. The player's record including scores is maintained across multiple play instances. A nearby desktop monitor serves as a scoreboard which lists the ranking of all player records for people to check. Note that for a non-study situation, we could choose not to require a log-in process to allow for anonymous play.

At all times, one or two researchers were in the deployment space, recording observations and conducting impromptu onsite interviews with players and spectators. The players' interaction with the game was logged by the system and video recorded. After each week of study, semi-structured follow-up interviews were conducted with several players selected from among those who opted to leave their contact information when they first played. Selected interviewees included players with the highest scores at the end of the week, as well as representative players covering different behaviors and backgrounds based on researcher observation during the week. As compensation, the interviewees were awarded prizes. To some extent this also served to encourage people to start or return to play. Interviews were conducted individually or in groups of 2-3 players who played together. Interviews were coded using open coding. Two researchers first jointly coded 2 randomly selected transcripts from each week in order to establish baseline agreement. One researcher then coded all 21 interviews transcripts, resulting in 571 unique codes, organized into 5 major themes as reported in the findings section. Limited by time, the second researcher randomly selected and coded 3 interviews to establish inter-rater reliability (IRR), resulting in observed agreement of 97.6%, and Cohen's Kappa of 0.662 averaging across all codes, indicating good agreement between the coders.

FINDINGS

A total of 239 people played *Flashlight Jigsaw*: 28 in Week 1 and 211 in Week 2. We interviewed 11 players from the shared laboratory space in Week 1 (noted as P1-1 ~ P1-11). All 11 were male computer science graduate students, researchers, or software engineers aged 23-31. We interviewed 16 players from the public atrium space in Week 2 (noted as P2-1 ~ P2-16). Of these, 6 were women and 10 were men, aged 17-25 and were undergraduate and graduate students from departments including engineering, computer science, psychology, nutrition, and biology. We use the themes derived from analysis of the follow-up interview transcripts as a primary framework for describing our findings. We situate these themes in conjunction with other data sources including observations, onsite interviews, and system logs, to provide a holistic understanding.

Game Play

Players unanimously liked the game experience, which was described as "*fun*", "*enjoyable*", "*cool*", and "*rewarding*". They particularly liked that the game was simple to understand and operate (20/27: 20 out of 27 interviewees explicitly mentioned, similarly denoted hereafter), and that they could play and communicate with other players (17/27). The game was also perceived as casual and lightweight (6/27), thus enabling other activities such as conversation with spectators.

The large size of the display appeared to be an important factor in the game experience (8/27). It was mentioned that in other co-located multi-player game settings such as arcades, the screen is usually occluded by the player's body, making it hard for spectators to be involved. The large size also contributed to a more immersive playing experience ("*Feels like you are a part of the puzzle*"). A few players even suggested deploying the game on even larger scale displays such as a movie theatre screen, which could enable a massive number of players to participate.

The main complaint related to imperfections of the tracking system, which resulted in the occasionally noisy or lagging controls (20/27). The freehand pointing and standing

posture were tiring after long plays (6/27). Suggestions for improvements include adding sound feedback, additional visual cues such as jigsaw edges on the pieces, and that the puzzle difficulty should adapt to players' experience levels.

Motivation to Play

Several factors contributed to a person's decision to play:

Novelty and curiosity (17/27): The majority of players were attracted by the novelty of the game and the technology when they first passed by, a common phenomenon to new activities and installations in public. However, 46 players played more than once, indicating that the game had an attraction beyond initial curiosity.

Entertainment and sense of accomplishment (17/27): Like any other game, the entertainment value itself is a major reason that people played. In addition to having fun, the sense of accomplishment gained by leading or defeating other players also contributed to people's desire to play.

Filling gaps in life (14/27): The game served as a relaxation tool when people took breaks from work or study. At other times, the game helped to occupy people between daily activities, such as when waiting for classes to begin.

Influenced by other players (16/27): Influence from other players played an important role in encouraging people to play. This included being invited by other players; joining when noticing other players; joining to help other players; or using the game to socialize with friends or strangers.

Prize incentive (7/27): Unsurprisingly, the prize incentive also played a role in encouraging people to try the game and seek higher scores. However, no interviewees considered it to be their primary motivation.

Collaboration and Competition

The game required all 3 controllers to complete the puzzle. While a single player could switch between multiple controllers, the most effective way to complete the puzzle and achieve a high score is to collaborate with other players. However, each player acquires scores individually, which potentially instills a sense of competition between players. This design decision enables both collaborative and competitive behaviors to emerge.

The game yielded a mixture of play styles. Many players reported they primarily played in a collaborative way (14/27), while others reported they played competitively (4/27). Of particular interest are the players who played both competitively and collaboratively at different points in the game (9/27). Competitive play occurred primarily between people who already knew each other, whereas collaborative styles were frequent between both acquaintances and strangers. Players also adjusted their play style depending on who they were playing with.

Players orchestrated their collaboration mostly verbally. They gave directions and suggestions ("*That piece goes to the bottom-left corner*"), and shared information with other players ("*There's a block of your color here*"). When needed, players also coordinated their actions, such as moving their flashlights synchronously to search for the star pieces. Some players would also assist others to finish certain tasks, such as moving irrelevant pieces out of the way, or shining the flashlight to let others grab a star piece. Players who played collaboratively thought it was "*fun*", "*enjoyable*" and "*relaxing.*" Friendly collaborative game play appeared to fit the casual setting of the game: "*...when I rest, I don't want to be so competitive. I just want to relax, so this collaborative game is appropriate for this situation*" (P1-1). People also valued the sense of working as a team: "*I had a team that started to work together better ... it was definitely rewarding*" (P2-16). The game scoring system also encouraged collaboration: "*We all get points after we're done. Then, we can get more puzzles then*" (P2-2).

When playing competitively, players employed various strategies to maximize their own scores' and/or minimize others'. This was not necessarily for pragmatic reasons such as winning a prize, but rather for the enjoyment of competition itself: "*It's always fun to be a little better than somebody else*" (P2-9). Some of these competitive strategies were: playing as fast as possible to overrun others; completing the public pieces first and saving pieces of one's own color for later; creating obstacles and inconveniences for others; or even deceiving others. The most frequent behavior was that in the end of a puzzle, each player would capture one piece, and all players wanted to be the last to release the piece in order to gain the higher completion bonus. This caused a temporary stalemate until someone conceded. Some reported that the desire to increase their scores and defeat others motivated them to play repeatedly (7/27).

Communication

The rich inter-player interaction in the game resulted in constant communication between players during most game sessions. The communication was mainly verbal, but also included body language such as pointing (with finger or flashlight) and gestures, which was made possible and necessary by the large size of the public display.

Most in-game communication was directly related to the game play and involved giving directions and suggestions, asking for help or input ("*Somebody give me a little light*"), or coordinating actions ("*Let's search some other area together*"). While more direct and imperative statements were also observed in some cases, ("*Stop moving my piece*", "*Drop it!*"), these were delivered in a friendly manner. Both one-way directive sentences and back-and-forth conversations were frequent. Communication tended to increase towards the end of each puzzle, when the players needed to concentrate in the same area or pieces, whereas in the beginning players acted more independently and required less communication.

More experienced players often voluntarily tried to explain and teach the game to new players. This happened regardless of the player being collaborative or competitive.

This spontaneous propagation of game knowledge helped to lower the entry barrier for the game, and created a welcoming atmosphere. The teaching behavior itself was also considered to be a rewarding experience by the players.

The game also provided an opportunity for players to make small side talk and to socialize briefly, which often happened when somebody had just joined, or to fill the gaps during the game, e.g. when a player did not have an available piece to move. The puzzle pictures also provided a frequent chatting topic ("*Look it's Aladdin*", "*I grew up with it [Disney]*"). These non-game-related communications tended to be short and opportunistic. But interestingly enough, a few players mentioned that during the few occasions of a system outage, they did have a chance to have extended chats while waiting for the system to recover, which also helped to ease the wait.

The in-game communication was found smooth and enjoyable by many players (21/27). One mentioned that the good communication experience during the game made him more confident talking to people in general: "*Usually I wouldn't have the initial to talk to someone at a public event… Playing the game definitely made me more confident*" (P2-1). For players who did not know each other previously, the amount of communication tended to increase over the period they played. The game served as an icebreaker between people: "*We sort of got to know each other and got comfortable with talking with each other so it was a lot more fun by the end*" (P2-13).

In addition to communication during the game, players also communicated about game-related topics later. While most after-game conversations happened between players who already knew each other before playing, there were also cases where strangers continued talking after they left the game, potentially providing a basis for further socialization. One player also tried to advertise the game to other friends through word-of-mouth and e-mails.

Social Interaction

Alone vs. Together

Most players preferred playing with others (25/27), of which 10 said they would not play the game if they were alone. This was partly because all 3 controllers were needed to complete the puzzles, requiring a single player to switch between controllers (although several players became skilled in this). However, social interaction was considered the main reason for preferring multiple players (18/25): "*Playing with other people, like I said, you feed off the fun that they're having*" (P1-8), "*[if played alone] then it's just like any other puzzle at home*" (P2-3).

Players indicated that puzzles were easier to complete and that they played longer when with other people, claims we validated by system log data. In both weeks, as the number of concurrent players increased, average completion time decreased, and average length of play session (time between when a player joined and left) increased (Table 1).

Table 1. Influence by number of players.

Number of players	1	2	3
Avg. Puzzle completion time (minute)	7.1	6.5	3.7
Avg. Play session length (minute)	6.5	10.5	12.2

Group Behavior

Players who played together can be considered to be a spontaneously formed group. Players implicitly assumed different group roles such as leader or follower without explicit assignment, Players also adjusted their group roles according to others' behaviors, e.g. choose to follow or lead depending on whether there was already a leader or not.

In Week 2 (public atrium), often a group of 2 or 3 friends arrived together and wanted to play. In the case that there were not enough available spots for them to join together, they would often choose to wait until some player left, rather than split the group. Comparably, in Week 1 (shared lab space), players often tried to recruit a group before starting to play. Most of the time, the group would continue playing until all players left together: "*It's a team game. If you leave, probably they will give up*" (P1-1).

Sometimes, we observed in-group isolation, i.e. two players who talked to each other while isolating the third. Reasons for this included: two players knew each other (better) but not the third player; one player fell behind because of lower skill or technical difficulty; one player closely interacted with a spectator, which isolated herself from other players; or one player's competitive strategy resulted in isolation.

Joining and Inviting

In addition to the individual motivations we mentioned previously, many players decided to join because other people were playing or going to play. New players frequently watched others play before joining. For returning players, the presence of others lowered the barrier to further play ("*Saves me some time to recruit people*"). This happened particularly frequently in the shared lab of Week 1, where there were not constantly people playing; it was not always easy to recruit partners because of the smaller population and work-oriented nature of the lab. However, the lab members who worked near the game installation would join when they saw or heard other players ("*If I hear a game I would move in for the kill*"). Those who walked through the room to pick up printouts or coffee got sidetracked to play if others were playing.

Players frequently invited others to join, either before they started to play, or in the middle of their games. Many players invited others for pragmatic reasons, such as to find hidden pieces or increase their scores, especially when they encountered a bottleneck in the game (9/12 of the interviewees who invited others); players also invited others to improve their game experience, given more players generally resulted in more fun (4/12); they also wanted to invite other people, either friends or strangers, to share the game experience that they enjoyed (6/12). The invitation was ad hoc, especially when in the middle of a game. Spectators were frequently invited to play, and general

invitations were sometimes yelled out ("*Anybody wants to join me?*", "*We need one more brain!*"). In addition, in Week 1 there were several cases that a person wanted to have a break from work and invited his officemates to go to play together. In Week 2, one player went to the student common room to invite her friends to try the game together, who then played and remained as a group. Compared to people invited by the game facilitator, invitations from players were more successful.

Socializing

Brignull and Rogers [4] explored using public displays to elicit socializing behavior between people. *Flashlight Jigsaw* had a similar effect to a certain extent. People tried to initiate socializing conversation when new players joined or during gaps in the game: "*It was an excuse to socialize briefly with lab members that I don't talk to so much*"(P1-5).

Interestingly, the game provided a tool through which players learned about other people's personalities, both for friends and strangers (11/27): "*I guess that <P2-3> is a little more aggressive than we thought.*" (P2-5). These impressions were often strong, such that in Week 2, 6/16 players recalled particular strangers they played with.

Although the game served as an icebreaker to initiate socializing, players' concentration on the game play impeded further socializing behaviors within the game itself. Players also said that the deployment spaces we chose were not particularly appropriate for follow-up socializing. They suggested that spaces where people would linger longer such as parks or cafes would better accommodate this.

Spectating

The nature of public display games ensures that spectating will always be part of the experience. We investigated the experience of both spectating and being spectated, through the follow-up interviews of players who also spectated, onsite impromptu interviews of spectators, and observations.

Reasons to Spectate

The reasons that attracted people to spectate were as diverse as those for playing. To list the most important ones:

Novelty (8/19 of interviewees who also spectated): The novelty of the game and technology stopped passersby wanting to figure out what it was. Some people also wanted to learn the game through watching before they played.

Puzzle and picture (9/19): Interestingly enough, many spectators simply enjoyed watching how jigsaw pieces went together, which was described by one player as "*mesmerizing*". The curiosity about what the final picture would be also caused people to stay and watch. The choice of Disney pictures seemed to echo well with many spectators.

Attracted by players (10/19): Players' performance and behavior served as the biggest attractor. Spectators enjoyed watching players both excel and struggle, as well as the interaction between the players. The excitement of the players also appealed to passersby. In particular, people were more attracted to spectate when they saw players they knew.

Attracted by other spectators (2/19): Like Brignull and Rogers [4], we observed the "honey-pot" effect: hurried passerby slowed their pace to observe the game, and as a larger mass of people accumulated around the display, more and more people joined them ("gravitation" effect).

Waiting to play (10/19): People who waited for spots to play usually watched other players while they waited.

Spectator Behaviors

There were relatively few spectators during Week 1 given the small and static population. In Week 2 there were always spectators whenever players were present. The number of spectators depended heavily on the time pattern in the building, ranging from 1 or 2 in light times, up to 30-40 when classes began or ended.

Spectators chose different standing positions to reflect their willingness to interact with the players. People who did not want to be involved watched quietly from afar, while those who stood near the players usually tended to communicate with them, especially when they knew some of the players.

Spectators' communication with players included directions and suggestions, commenting on the players' performance, and asking players about the game. In particular, some players consulted with their spectating friends on what moves to make, often resulting in a "co-playing" situation.

There was also frequent discussion amongst spectators. Much of this was commenting on the players and discussing puzzle solutions. Former players or more experienced spectators also often tried to explain the game to other spectators. This increased the public awareness of the game and potentially prepared more people to play.

We also observed "quasi-spectator" behaviors, where people stayed in the deployment area and watched the game, while engaging in other activities such as having their own conversations or eating lunch. The game acted almost like a "water cooler" to create a social hub for people to linger in.

Being Spectated

Players had different attitudes about being watched. Some did not care (12/18 amongst the interviewees who noticed being spectated), while some particularly enjoyed spectators' presence (7/27), partly out of the desire to show off ("*Hey, check out my skills!*"), and more importantly because the spectators contributed to the excitement in the atmosphere: "*It really reminds me of Dance-Dance Revolution because it's not just the two people who are dancing who are part of the game, but it's pretty much everybody around who's cheering them on or looking at them*" (P1-11).

The presence of spectators also influenced players' behavior and attitudes while playing. Some players felt distracted, nervous, or intimidated if there were many spectators (10/27), especially when they were performing badly or being discussed. Conversely, players tried to

perform better or more cautiously when being watched (4/27) (the social facilitation effect [22]). No interviewee explicitly opposed to being watched given the public setting of the game, as one player noted: "*If I'm playing in a public space, I'm prepared for other people watching me*" (P2-1).

Spectating and Playing

Many people experienced the game as both spectators and players at different times. In particular, many people started as spectators and then joined the game. The transition from a spectator to a player was smooth (9/14 of the interviewees who both played and spectated), partly because the spectator learned about the game as well as the players' strategies through watching. Spectating also encouraged people to start playing themselves, and performance of other players encouraged them to do better when they played (6/14). This ease of movement between spectatorship and playing appeared to be critical to the success of *Flashlight Jigsaw*.

Space and Location

Playing electronic games in public spaces with ad-hoc partners was a novel experience to most players, although many of them did so with real-world games or sports. Some players had played games on personal devices in public, alone or with a few friends. Compared to this, the public display game created a shared experience involving all people in the space. Similar to the findings by Brignull and Rogers [4], the few interviewees who had experience with public displays stated social embarrassment as the key factor that prevented them from playing ("*I didn't want to seem dumb*"). In *Flashlight Jigsaw*, the presence of other players helped alleviate the concern and made the public display more socially acceptable: "*I'm not too worried about doing it because other people are doing it like me*" (P1-9). The fact that players were co-located in the space (compared to online games with remote players) also added to the game experience because of the rich communication and interaction involved (13/27): "*It's a little dangerous to remove yourself from all your contacts and sit in a room by yourself, so having people there with you and really engaging with them and communicating is more fun… it would develop their communication a lot better*" (P2-16).

Players generally thought the deployment spaces were appropriate for the game given the regular traffic in them (18/27). Their pre-existing knowledge that the building housed computer science and engineering departments may have prepared people for seeing these kinds of installations. However, this also means the population in the spaces was relatively uniform, mainly consisting of university students with reasonable technology experience. More diverse populations would be present in more general public spaces such as parks or plazas. Nevertheless, among the players were representatives of various age groups, including 3 elderly people. One elderly woman initially shied from the technology ("*Could work for teenagers, for me it's much easier to play on a table*"), but as she watched, she began to give the players suggestions, and finally grabbed the controller from a player to start playing herself. The spectators included various employees who worked in the building, such as janitors, cashiers, and electricians.

Players considered the game suitable for playing for short sessions in a casual manner (11/27), which nicely fit in their life patterns in public spaces. The presence of the game also changed people's experiences of the spaces themselves (9/12 respondents to a follow-up email). The spaces became more "*social*", "*vibrant*", "*relaxing*", and "*approachable*", as opposed to "*boring*", "*dead*", and "*empty*" before the game deployment. For some people, the technology caused them to vary a pre-established walking path: "*After I knew that the game was where it was set up, every time I had a class in the building, I would want to pass by.*" (P2-7) The spaces were converted from a passageway that people only passed by into a social hub where people would stop, meet or come purposely. As a result, the spaces themselves also received more attention during or even after the deployment: "*(I noticed) there exists a payphone underneath the stairs, but after walking around the building for almost every school day for the last 4 years, I've barely noticed it*"(P2-1), "*Whenever I walk past the large display, it reminds me of the different puzzles that I played with my colleagues*" (P1-8). A study of public plazas [20] found that the successful public spaces were those that "stimulate people into new habits – al fresco lunches – and provide new paths to and from work, new places to pause". Similarly, public display games encouraged people to form new life patterns around a space that was otherwise banal or irrelevant to them.

Conversely, in Week 1 the proximity of the game to work spaces was occasionally disturbing: "*When I was deep in thought or in 'work mode' I would sometimes be annoyed at the pandemonium happening in front of the game*" (P1-9).

Given the different characteristics of the two deployment spaces, players also showed different behaviors and playing patterns. In addition to those discussed earlier, Table 2 summarizes the player records throughout each week of game deployment.

Table 2. Playing pattern statistics.

Week		1	2
Space		Shared	Public
Number of players		28	211
Number of play sessions per player	Mean (SD)	2.86 (2.69)	1.26 (0.99)
	Median	1.5	1
Total playing time per player (minute)	Mean (SD)	26.6 (29.0)	23.9 (29.1)
	Median	16.0	10.0
Completed puzzles per player	Mean (SD)	5.64 (6.99)	2.91 (5.72)
	Median	3	1
Play session length (minute)	Mean (SD)	9.6 (7.9)	13.0 (11.3)
	Median	7.1	9.5

In the shared lab space of Week 1, people played more frequently (also reflected in more total playing time and completing more puzzles) but in shorter sessions. The vicinity of the game to players' work areas resulted in the

relatively "frequent and short" playing pattern, as opposed to the public atrium in Week 2, which had a more dynamic and transient population. The existing social relationship between the people in the lab also resulted in more plays influenced by other players. We expect other different playing patterns and behaviors would emerge if the game were deployed in other public spaces such as cafés or parks.

DESIGN IMPLICATIONS

Our study indicates that *Flashlight Jigsaw* was a successful multi-player game for public displays, thus satisfying our initial design goals. We expect many of these findings could generalize to other public display games. Based on them, we draw some design implications for improving the experience of *Flashlight Jigsaw* as well as public display games in general.

Encouraging Initiators

We found that existing players acted as a strong attraction for other people to play public display games. However, during our study when there were no other players present, first-time players often needed invitation or encouragement from the game facilitator to take the initiative, although some were already interested due to the game display or the poster. The encouragement from a real person was much more effective than lifeless messages on the display. For long-term real-world installations of public display games, which would ideally not require a human facilitator, we could consider using on-screen conversation agents to invite players. For example, when nobody is playing, the display can show an animated or recorded character. The character starts to talk and invite people to play when optical or acoustic sensors have detected passersby. The life-size of the personated character on the public display could potentially produce the similar effect of a real inviting person. Similarly, Vogel and Balakrishnan [19] explored showing an onscreen video of a person on public displays, but used it for explaining system operations only.

Promoting Socialization

Flashlight Jigsaw acted as an icebreaker to initiate socializing, but did not further accommodate it very well. The concentration on the game itself distracted players from holding conversation about other topics. However, we did observe players socializing during the gaps of the game such as an occasional system outage. Inspired by this, we could consider a "gapful" design, i.e. intentionally introducing gaps into the game. Real-world games often have this gapful nature, often reflected in turn-taking such as in billiards, which was mentioned as a good socializing tool by players. Similarly, turn-taking or periodic breaks in the public display game could provide opportunities for players to socialize. However when doing so we must be cautious not to compromise the game flow and dynamics. On the other hand, the game itself could be designed to include themes for people to chat about, just like the Disney pictures in *Flashlight Jigsaw*. By doing these, we could make these games a more effective platform for socializing.

Improving Single-Player Experience

The single-player experience in *Flashlight Jigsaw* was considered inferior to the multi-player experience. The controller switching procedure was annoying enough for some players to give up. In our design it was difficult to balance between improving single-player experience and encouraging group playing, and at the same time supporting seamless transition between the two. We expect this to remain a challenge that has to be addressed for most public display game designs, although the specific solution will vary from game to game. One general possibility is to have automated "ghost" players controlled by the system to group with single players, which will be replaced by real players as they join. The ghost players could be combined with on-screen inviting agents mentioned previously.

Facilitating Group Forming

In addition to spontaneously joining a game, players also enjoyed forming a group before starting. Without sacrificing the ad-hoc nature, we could provide tools to deliberately facilitate this group forming behavior. For example, a matching service could help individual players seek out game partners by sending text messages to interested parties in the vicinity. The game could also maintain group profiles for more persistent groups over time. The game should also support a more volatile number of players so a group can always join together without having to wait for spots.

Designing for Spectatorship

Spectator experience around the game is an inseparable part of public display games. Based on the taxonomy proposed by Reeves et al. [14], the spectator experience of *Flashlight Jigsaw* was "expressive", where both the operations and the effects of the player actions were revealed to the spectators. This enabled the spectators to enjoy and comment on the players' behaviors, as well as prepared them for playing. To further improve the experience of spectating as well as being watched, we could consider introducing participation from the spectators in the game, for example letting spectators vote on players' performance using their personal devices. On the other hand, the game could include a "spectator" mode that plays by itself, allowing people to spectate even when nobody is actively playing. In this mode the game (or the ghost player) may occasionally ask for input from spectators, resulting in intermediate levels of involvement, and potentially elicit spectators to start playing. We could also capitalize on the collaborative relationships between players and spectators. For example, the game could require additional attention, so having a spectating advisor ("spotter") would be the best way to win.

Situated Design

As we showed, people's game experience and behavior were largely influenced by the spaces where the game was deployed. For public display games to successfully blend into public spaces, the nature of the space itself needs to be accounted for in the design: How big is the space? What is

it used for now? Is it indoor or outdoor? Is it noisy or quiet? How many people are there? Who are they? Do they know each other? Are they standing or sitting? Are they familiar with the space? Answering these questions would help to situate the game design in the space from the beginning, and guide the decisions we make throughout. In addition, we need to consider what roles the game will play in the space, be it for people to kill time while waiting, for people to relax from work, or for attracting people to gather in the space, and so on. The same game design could result in various experiences in various spaces.

CONCLUSIONS & FUTURE WORK

We presented a detailed exploratory study of a multi-player public display game deployed in a public and a shared space. We explored the game experience and social behaviors of both players and spectators from several aspects. The *Flashlight Jigsaw* game proved to be a successful exercise in designing games to be specifically played on public displays. The findings and design implications resulted from our research could apply to other public display games in general, and guide future designs of such games. Our results also suggest that multiplayer gaming is a strong candidate for establishing public displays as a compelling interaction platform.

In the future, we plan to explore other design possibilities of public display games, especially those which support a larger number of concurrent players. We are also interested in deploying these games in spaces of different natures, especially outdoor spaces, to further understand how spaces influence the public display game experience. Finally, as the technology becomes more viable, deploying *Flashlight Jigsaw* using its inspiring technology – handheld projectors would create an interesting overlapping experience between mobile and public display games.

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