Understanding the Interplay Between the Digital and the Physical in Shared Augmented Reality Gaming: Probing through *Urban Legends*

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Shared Augmented Reality (Shared AR) is an emerging technology that enables multiple users to interact synchronously within a collocated AR environment. Yet, there is limited research on the group interactions and dynamics in Shared AR, particularly in the context of gaming. To address this gap, we investigate Shared AR group interactions using a phone-based Shared AR mobile game called *Urban Legends*. Through in-situ observations, focus groups, and one-on-one interviews with 22 participants, we examine how users collaborate and communicate within the game. Our findings reveal that while verbal communication predominates, non-verbal cues are often overlooked by collocated participants, and users initially struggle to recognize the expansive virtual space and the need for physical movement. Over time, users adapt to the hybrid environment, demonstrating increasing spatial awareness and more dynamic collaboration. Based on these insights, we present a suite of design recommendations for enhancing spatial awareness, supporting multi-modal communication, and fostering engaging group dynamics in future Shared AR applications.

CCS Concepts: • **Human-centered computing** → *Social networks*; *Computer supported cooperative work*; **Mixed / augmented reality**.

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1 Introduction

Augmented Reality (AR) is an increasingly prominent technology that integrates digital and physical worlds, reshaping how people work, socialize, and learn [5, 15, 40]. As AR applications have continosly mushroomed and permeated various aspects of daily life, a growing body of research in human-computer interaction (HCI) has emerged to explore multi-user AR and its potential to support more complex and collaborative interactions [15, 36, 52, 60].

In a multi-user AR experience, a group of users interact within an computer-mediated environment, whether collocated, remote, or physically distributed, leading to more complex, dynamic, and adaptive interactions compared to single-user AR [3]. Recently, the HCI community has shown growing interest in the challenges and opportunities of AR-supported group dynamics [36, 60, 61]. Building on this ongoing discussion, our work aims to provide empirical insights into these group interactions. In the present work, we focus on *collocated* group interactions in what we term *Shared AR*, where users share the same physical space while engaging in collaborative digital tasks. This leads us to our central research question: *How do users interact within the Shared AR space, and how does this shape communication and collaboration?*

To explore this, we adopt a probe-based approach [23, 43], using *Urban Legends*, a Shared AR mobile game, as a research probe. In HCI research community, probes are used to provoke responses, surface latent behaviors, and generate insights that might not emerge through conventional methods [23]. By positioning *Urban Legends* as a probe, we aim to observe how players navigate in the physical space, adapt to AR-mediated interactions, and develop communication methods and collaborative strategies. *Urban Legends*'s gameplay is designed to encourage collaboration through a playful multi-user experience, making it a suitable context for exploring group interactions. In general, games provide a structured yet flexible environment where user behaviors naturally emerge, making them valuable for studying social interactions and dynamics [2, 16, 68].

To develop a rich understanding of user perceptions and behaviors in Shared AR, we conducted a contextual inquiry to explore how groups interact in Shared AR during *Urban Legends* gameplay. Our study involved 22 university students (strangers at the beginning), divided into four groups, who played *Urban Legends* in person for five rounds. Each in-person group play session lasted for roughly an hour. After each in-person group play session, we conducted focus group discussions and semi-structured one-on-one interviews with participants.

In sum, our work makes the following key contributions:

- An empirical understanding of users' spatial perceptions in Shared AR: Our findings reveal that users initially overlook the expansive virtual space beyond the display screen and are unaware of the need for physical movement to navigate it. Over time, spatially collaborative game design guided users to develop and adapt to Shared AR spatial awareness.

- An empirical understanding of users' communication and collaboration behaviors in Shared AR: Our findings demonstrate that verbal communication dominates in Shared AR, while non-verbal communication is often overlooked.
- Design implications for enhancing user experience in Shared AR: We propose design solutions to scaffold spatial awareness, balance visual attention between virtual and physical spaces, support multi-modal communication, and engage non-players in the experience.

2 Related Work

This section reviews three relevant areas of work: (1) Hand-held AR and Spatial Awareness, (2) Collaboration in Collocated Marker-less AR, and (3) Group Interactions in Shared AR.

2.1 Hand-held AR and Spatial Awareness

The proliferation of AR applications has introduced various display modalities, including head-mounted devices, handheld mobile devices, and spatial AR systems [14, 35]. Among these, handheld devices such as mobile phones have emerged as effective for AR experiences due to their lightweight design, integrated sensors, and ubiquity in daily life [1, 25, 32, 65]. Tango et al. [56] indicate that handheld AR can offer a more natural user experience compared to head-mounted displays, while it requires deliberate device movement to explore virtual spaces. Unlike head-mounted AR, where user perspectives shift seamlessly with the user's gaze, handheld AR requires conscious effort to explore the spatial environment by deliberately adjusting the device [46, 55].

Specifically, effectively representing off-screen objects in handheld AR is essential to enhancing both user experience and spatial awareness. Unlike conventional mobile phone usage, where interactions occur solely within the fixed boundaries of a screen, handheld AR requires users to physically move and orient their devices to align virtual content with their surroundings [58]. This dynamic interaction extends the user's engagement beyond the display, creating unique challenges for visualizing off-screen elements [30]. Previous works have proposed on-screen UI elements, such as mini-maps or arrows, to visualize these elements [58]. While these solutions can be effective, they may also introduce visual clutter and increase cognitive load, potentially hindering the user's ability to integrate virtual and physical environments. LaViola et al. [33] emphasize the importance of minimal AR on-screen design to prevent visual fatigue, suggesting that adding more UI elements may not always be the optimal solution.

In addition, the AR experience provides a dual layer of information for users to perceive and interact with. Consequently, the AR experience might influence how players perceive their surroundings, potentially leading to changes in movement-related behaviors within such environments [7]. In particular, the phenomenon of attentional tunneling [67], where users focus excessively on virtual content at the expense of awareness of the physical environment, has been observed in handheld AR contexts. Parmar and Silpasuwanchai [50] found that user mobility amplifies this effect, leading to increased reaction times to real-world events. This underscores the need for AR designs that balance virtual engagement with environmental awareness, especially during movement.

Building on these observations, there is a need for empirical studies to understand how users perceive and navigate AR environments, both on-screen and off-screen, and how they interact with the dual layers of reality. To this end, our research focuses on handheld mobile AR, aiming to delve deeper into user perception of AR spaces that extend beyond the phone screen and to analyze movement behaviors within such environments.

2.2 Collaboration in Collocated Marker-less AR

A key advancement in handheld AR technology is the development of marker-less AR [28]. Unlike marker-based AR, which depends on predefined physical markers, markerless AR provides greater flexibility, making it more accessible to a broader audience [69]. Compared to marker-based AR, marker-less AR allows more fluid responses to users' bodily movements but remains a developing technology undergoing usability testing [21, 37, 59].

At the core of marker-less AR is Simultaneous Localization and Mapping (SLAM) [20], which enables multiple devices to capture visual and depth information, creating a shared spatial understanding among collocated users. SLAM systems integrate inertial visual sensors (e.g., mobile phone cameras) into a global map that is continuously updated and shared across connected devices [59]. These peer devices operate through a peer-to-peer connection, where the first user (Host) records the environment and shares the spatial data with subsequent users (Guests) via the internet [18]. We refer to this process as *localization* in our work. Notably, localization is recognized as a challenge for users to set up on their devices [59] and inherently introduces a collaborative task, as users must collectively complete it before engaging in the AR experience. The challenges and opportunities of collocated marker-less AR experiences–termed "Shared AR" in this work–are still unfolding.

Although Shared AR experiences have been explored in domains such as entertainment [16], education [8], and social interaction [48], previous studies have explored AR's impact on individual engagement in collaborative tasks [17, 22, 38], the specific dynamics of multi-user collaboration in AR environments remain underexplored. Unlike pure in-person collaboration [10] or remote collaboration in a virtual environment [9], Shared AR requires users to collaborate in a space that dynamically integrates physical and virtual interactions. This study investigates how Shared AR fosters collaborative interactions among users in a collocated setting.

2.3 Shared AR as Public Social Play

Movement-based play in public spaces fosters rich physical and social experiences [26, 27, 42, 51]. Shared AR introduces a new form of movement-based social play in public spaces, differing from traditional public games such as Yamove [26], which rely on a shared public screen to display all players' states. In contrast, Shared AR operates through independent devices, meaning each user experiences a unique perspective of the space.

This shift introduces a key collaboration challenge: ensuring that all users develop a shared understanding of the AR environment [6]. How users communicate and coordinate in public AR spaces remains underexplored. Prior research on public social play suggests that personal territoriality in physical spaces [31, 49, 66] may influence group interactions, raising questions about how spatial boundaries shape public play in Shared AR.

Beyond direct participants, spectators also play a role in Shared AR. Prior literature in digital gaming suggests that spectators contribute to interaction through continuous scaffolding—offering guidance, commentary, or encouragement [62]. However, location-based games, a genre of mobile games played in public, have also been shown to create tensions between players and non-players [11, 68]. Since non-players lack access to the game view, they can only observe players' gestures and movements, leading to misunderstandings and confusion. Players, in turn, may feel awkward or self-conscious, highlighting the need for designs that enhance the social acceptance of AR experiences in public settings. To this end, further research is needed to explore how Shared AR, as a new form of public social play, aligns with or challenges existing understandings of social play dynamics.

3 Methods

3.1 Playful mobile Shared AR application: the research probe *Urban Legends*

To empirically explore users' spatial perceptions and collaborative dynamics in Shared AR, we used *Urban Legends* as a research probe. Developed by Niantic in 2021 for Android mobile phones, *Urban Legends* has not yet been publicly released, but we were granted early access for research purposes. The game supports up to six players, who collaborate to rescue an AR character called Yeti (see Figure 1) within a shared AR environment. The gameplay emphasizes teamwork and physical movement.

As shown in Figure 2, six users play *Urban Legends* as a group, each holding a mobile phone. The devices serve as portals between physical and digital realities, allowing players to view AR elements overlaid on their surroundings. Players navigate the space to evade AR enemies, using on-screen buttons to launch attacks and adjusting their phone angles to aim (See Figure 4). Once all enemies are defeated, players must collect AR keys by physically moving to their locations and delivering them to Yeti to complete the mission.

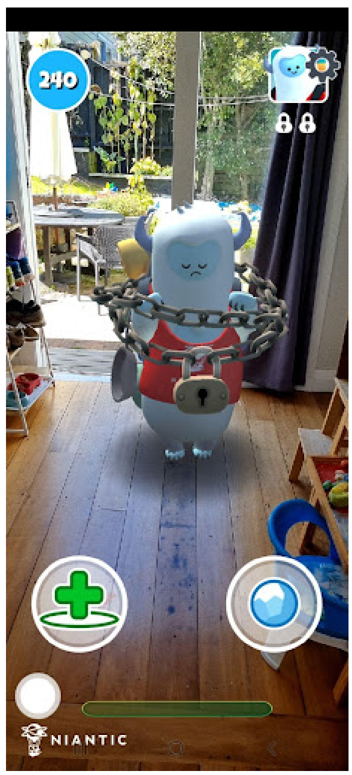

Fig. 1. AR Character Yeti in Shared AR *Urban Legends*

Before entering the gameplay, users have to complete the following setup steps (see Figure 3):

(1) **Create a new game session.** One player serves as the Host, while the others join as Guests. The Host taps "Start a new session," and Guests scan the QR code displayed on the Host's phone to join the game.

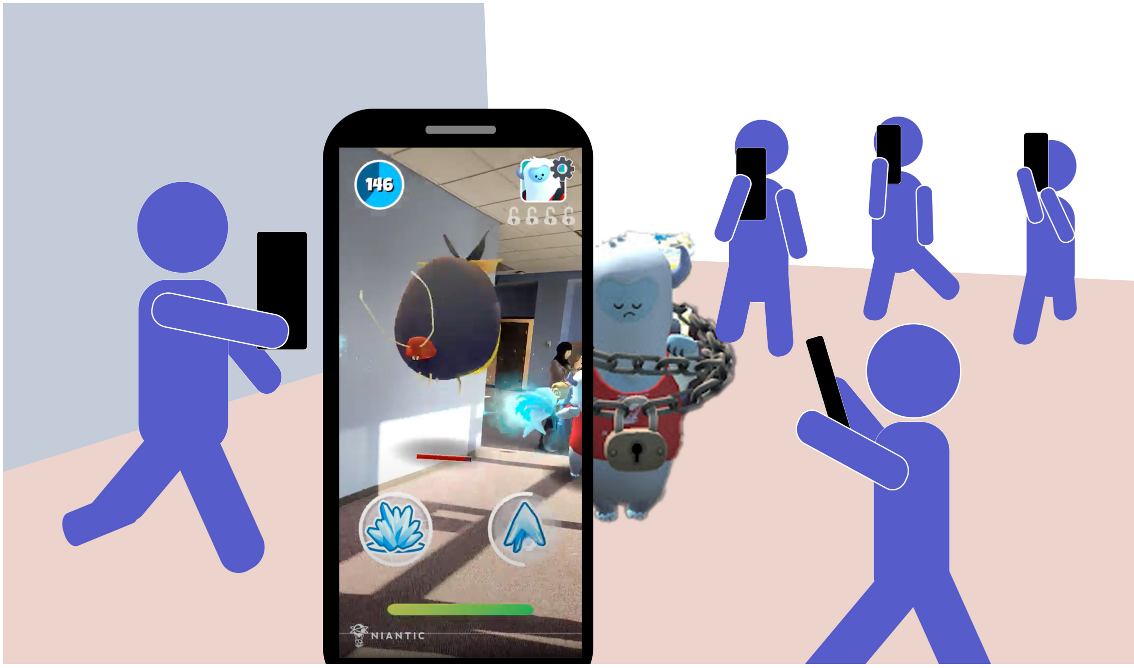

Fig. 2. An illustration of six users playing *Urban Legends* together. They are holding their mobile phones, viewing and aiming at AR components, clicking buttons on phone screens, and moving in the space. They have to defeat AR enemies and save Yeti collaboratively.

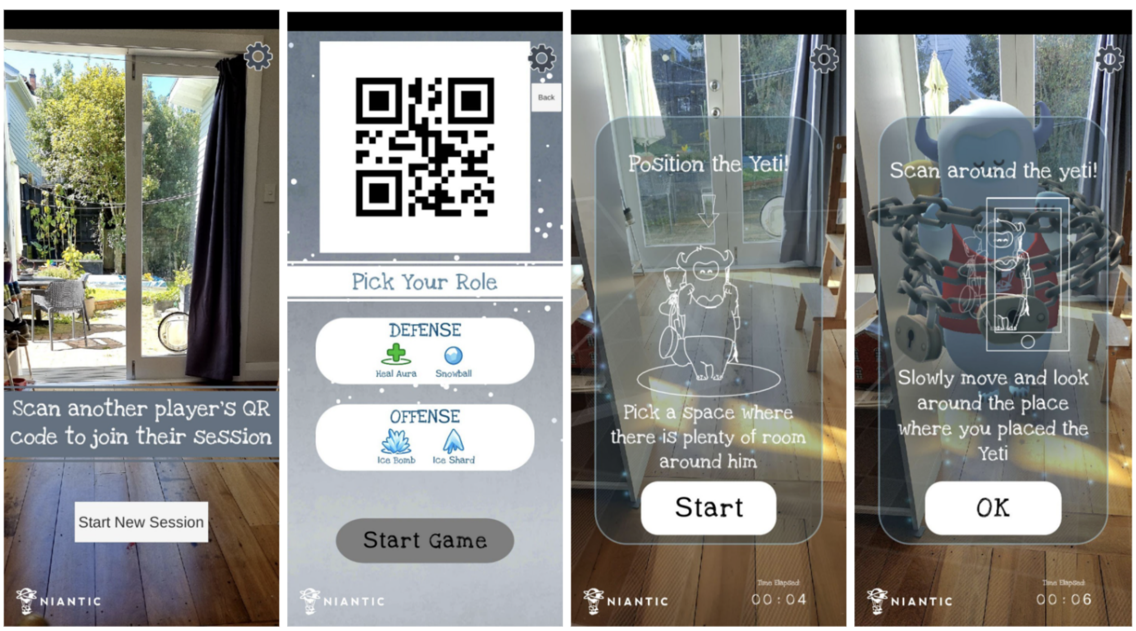

Fig. 3. Step-by-step Interfaces of *Urban Legends*: Host to start a new session, pick a role, localization

(2) **Pick a role.** Users select either “Defense” or “Offense,” each with distinct abilities. All players are on the same team and must collaborate to win. “Offense” specializes in attacking enemies, while “Defense” can heal nearby teammates within a short range.
(3) **Localization.** This Shared AR experience is location-agnostic, allowing players to select their preferred play area. The Host places the Yeti, the central figure of the game. Guests then scan the area where the Yeti is positioned until the game signals the localization is complete, ensuring all players’ devices are connected to the Shared AR.

Fig. 4. User Interfaces of Offense and Defense. Users can tap the round icons to launch spells. Each role has two spells. Screenshots from participants’ screen recordings.

3.2 Contextual Inquiry

We conducted a contextual inquiry to observe and interview participants in real-world scenarios while playing *Urban Legends*. This method aligns with three key principles [53] that support our research aim to obtain empirical understandings on user behaviors and perceptions:

(1) Data gathering must take place in the context of the users’ work.
(2) The data gatherer and the user form a partnership to explore issues together.
(3) The inquiry is based on a focus.

Typically, contextual inquiry involves two steps: observing users as they engage in an activity and conducting interviews to gather insights (e.g., [29, 54]). In our study, we observed participants during their gameplay sessions and conducted interviews afterward. To maximize the depth and breadth of insights, we employed both focus groups and one-on-one interviews. Focus groups held immediately after in-person gameplay sessions helped capture shared perspectives through group discussions, while one-on-one interviews provided a deeper exploration of individual experiences and perceptions.

Based on these considerations, we designed an experimental protocol consisting of three parts: (1) an in-person group gameplay session, (2) a focus group discussion, and (3) one-on-one interviews. Parts (1) and (2) took place in person, while (3) was conducted online via Zoom. Each participant engaged in the study for approximately two hours: one hour for the in-person group session, which included five rounds of *Urban Legends*, about 20 minutes for the focus group discussion, and around 40 minutes for a one-on-one interview. Participants received a 30 USD Amazon e-gift card as compensation. Data collection commenced following IRB approval.

3.3 Participant Recruitment

To facilitate the collocation of participants and researchers, we recruited university students. Recruitment was conducted through an email list that reached students across various majors and academic levels (undergraduate and graduate). The email introduced our research goals and experiment plan and included a survey to collect basic participant information and availability. This data was used solely for grouping participants, not for analysis.

We aimed for a balanced mix of gender, age, and prior AR and gaming experience. Additionally, we ensured that none of the participants knew each other before the study, as this allowed us to observe how new relationships and collaborations formed in Shared AR while minimizing potential biases from existing social dynamics. After grouping participants based on availability, we emailed six selected individuals per group. Each group had a gap of approximately one week to allow sufficient time to complete all interviews before starting the next session. The study was conducted between January and February 2023. We continued running group experiments until we observed that, in the latest sessions, no significant new insights emerged, indicating data saturation.

In total, we conducted four group experiments (Groups 1 to 4) with 22 participants: 7 females and 15 males, aged 18 to 34 (see Appendix A). Groups 1 and 2 each had five participants due to last-minute cancellations, while Groups 3 and 4 had six participants. Initial data analysis began after completing the Group 1 experiment, and after Group 4, we determined that data saturation had been reached, concluding data collection.

3.4 In-person Group Play Session and In-situ Observation

We conducted in-person group sessions in a campus building for three reasons. First, the Wi-Fi connection was more stable indoors than mobile data outdoors. Second, the weather was unsuitable for the Shared AR testing outdoors in winter. Third, campus indoor spaces had more non-participants (professors and students) walking through, which allowed us to observe the group interaction between users and non-users in the external environment, an important aspect in group interactions [3].

Before each in-person group session, we emailed the participants an installment package for *Urban Legends* and reminded them to bring a fully charged Android phone (no specific device model is required as long as it can run the Shared AR application). Two researchers guided the in-person group sessions. First, we provided a brief introduction to the study's purpose and an overview of *Urban Legends*, including its characters, localization process, and role dynamics. To minimize potential biases, we framed UL as a novel group-based game experience without specifying gameplay mechanics that might influence participant behavior, such as the need to move around or adjust their phone angles. This approach allowed us to observe how participants naturally discovered and adapted to the game's interaction affordances. Then we went to the corridor, which had enough space for the game sessions (note that every group played at the same place).

We asked participants to play multiple rounds to see how the group interaction changed over time. Based on our pilot study, we found that five rounds would take about an hour, which seemed a reasonable time for participants and for us to obtain sufficient data from the group. We video-recorded the whole process with the participants' consent, and two researchers did in-person observation and note-taking. We also asked participants to record their screens while playing, which gave us another data source to view their group activities and triangulate the observations. To be noted, we refrained from offering help to users when they encountered issues while playing *Urban Legends* because users would have to tackle application issues themselves when playing in real-world scenarios. Instead, we would take notes for analysis on any difficulties users encountered and how they solved them.

3.5 Focus Groups

After the five rounds of *Urban Legends*, all participants returned to our lab and we conducted a focus group. The focus groups were videotaped, and the first author moderated the process. Four prompts (i.e., in-group discussion, in-game collaboration, interaction with non-users and space, and issues) focused the discussion in the focus group (See Appendix B).

After each question, we invited each participant to answer it and allowed discussion among the group. For example, if two participants have opposite opinions, we would invite them to tell us why they have such different perspectives in the same group. Meanwhile, another researcher took notes and asked follow-up questions if needed. Each group spent around 20 minutes completing the focus group discussion.

3.6 One-on-one Interviews

At the end of the focus group discussion, we invited all participants to book a one-on-one interview with us. All interviews were conducted online via Zoom, were video recorded, and took place within a few days of the focus group. Similarly to the rigor of the focus group, the first author asked interview questions, and another researcher took notes. The interviews lasted, on average, around 40 minutes.

The interview followed a semi-structured format, adapted from prior research on group interactions in location-based games [11]. Unlike the focus group, which centered on collective discussions, the individual interviews provided a first-person perspective on group dynamics, offering a complementary viewpoint. We designed the interview questions (see Appendix **??**) to explore the following aspects:

(1) Social demographic questions (i.e., age, gender, and ethnicity).
(2) Prior game and AR experience.
(3) *Urban Legends* group interaction experience, including in-group, with nonusers, and with the external environment. We asked questions like "*How did you interact with non-players in your game area? Do you mind others looking at you when you play the game? Why or why not?*" and "*Did anyone encounter any difficulties in your group during the localization process? If yes, can you describe it?*"
(4) Expectations for future Shared AR experiences. For example, "*Are you willing to join Shared AR activities again? If yes, with strangers, families, or friends? Why?*"

3.7 Data Analysis

As mentioned above, we started the initial data analysis after we collected the Group 1 data by reviewing notes, listening to the focus group and interview recordings, and reviewing the video recordings. We reached data saturation after the Group 4 experiments. We transcribed the audio recordings into text through the Zoom caption tool and then corrected them manually.

Unlike deductive analysis, which applies predefined categories from existing frameworks, inductive analysis allows codes to emerge organically through direct engagement with the data [12]. Since no suitable coding framework existed for our study, we adopted an inductive approach. Our analysis was informed by several theoretical perspectives, including Arrow et al.'s Small Group Theory [3] and Mueller et al.'s Exertion Framework [44]. Arrow et al. define small groups as "complex, dynamic, and adaptive" systems that interact both internally among members and externally with their environment [3]. In a later study, Arrow et al. [4] introduce a temporal perspective, emphasizing that group interactions evolve over time. Mueller et al.'s Exertion Framework offers a lens for analyzing spatial perception in Shared AR by conceptualizing the human body through four dimensions: responding, sensing, moving, and relating. These dimensions provide useful perspectives for examining how users physically engage with and interpret AR environments.

We imported all transcripts into Nvivo 12 and managed data in groups. Specifically, we built four files for Groups 1 to 4 to store video notes, the focus group, and interview transcripts. Different groups' data were coded in parallel. In the first round of coding, we used the In vivo method [41], which creates codes directly from participants' own words. During the second round of coding, we chose the Patterns coding method [57] to categorize codes and create new codes. For instance, our in-person observation notes demonstrated that participants used a lot of body language, such as waving, but participants believed these behaviors were unconscious and ineffective. Thus, we coded the pattern "non-verbal communication."

After generating codes for each group separately, we analyzed cross-group differences and commonalities. As expected, most codes overlapped across groups, with variations primarily in game strategy details, such as different role allocations. Rather than emphasizing these strategic differences, we focused on identifying shared motivations and perceptions underlying players' decisions. The identified themes are further explored in Section 3.7. For anonymity, all participant names mentioned are pseudonyms.

4 Findings

4.1 Evolving Spatial Awareness and Movement Dynamics

In the first round, we observed that participants from all four groups tended to remain stationary in their initial positions, holding their devices still without adjusting their angles. For example, video data shows that, like many participants, Kevin stood in the same spot throughout his first round, using one hand to hold his phone steady while the other was used to click buttons to interact with AR objects on the screen. Kevin recalled and explained his behaviors during this initial experience:

> "The first round was really confusing for me. I didn't know that I needed to move around and look for flying enemies (AR objects) by adjusting the device's camera angle. I think the others were also clueless because they were just standing still and not changing their views." (Kevin, male, G4)

In fact, *Urban Legends* is designed to enable the player to move and angle their device to find and interact with other AR objects scattered throughout the spatial environment. However, participants initially lacked awareness that the AR extended beyond the immediate view captured by their device screens and did not try to change their view.

Since the design of *Urban Legends* required "Defense" players to heal "Offense" players within a very limited spatial range, players in different roles are guided to move in the space and closer to each other when healing is needed, which led to a shift of participants' spatial movements in the later rounds. This process gradually led to more dynamic movements and camera angle adjustments, indicating that participants were becoming accustomed to adjusting both their physical positions and device angles to better navigate and interact with the AR environment.

In addition to their initial unawareness of the movement aspect of Shared AR, participants hesitated to move at first due to concerns about maintaining social distance. As they became more familiar with each other in the later rounds, this hesitation gradually led to a closer physical proximity. Casey described her initial hesitation to move, concerned that it might cause her to encroach on others' territory since they were strangers at the time. However, as the game progressed, players became more comfortable moving and getting closer to one another:

> "You know, people just do not want to come too close to others when they are not familiar with them. So, in the first two rounds, we just avoided moving a lot because we didn't want to rush into others' space. But as time went by, we kind of reached the consensus that we were okay coming closer and moving freely around others nearby." (Casey, female, G3)

This progression highlights how movement design in Shared AR influences participants to shift from individual awareness to a more collective, dynamic engagement with both their physical environment and their teammates.

4.2 Visual Attention between AR Screen and Physical Surroundings

Shared AR integrates digital gameplay with the real world as a background, creating an immersive and engaging experience. Participants found this overlap between virtual objects and their physical surroundings to be a unique aspect of gameplay. As Rita described:

> "The game objects overlap with the real world; Yeti is standing on the carpet, and flyers are flying in the corridor, which made it very engaging and interesting for me. I can play a game in real life, and it feels very different from previous mobile games I played." (Rita, female, G4)

Most of the time, participants' visual attention remained locked on their phone screens, using them as a primary lens to perceive and interact with the mixed reality environment. However, we observed that players frequently and momentarily diverted their gaze away from the screen, scanning their surroundings directly. This behavior was particularly noticeable when they were in motion, as they needed to check for obstacles or maintain spatial awareness beyond the restricted field of view provided by their phone screens. Adrian explained this shift in attention:

> "I need to see my physical surroundings, whether there are things behind me or whether I might bump into others. Through the screen camera, I could not see wide enough compared to my eyes, and also, the screen had too many things going on. I really could not see my surroundings clearly (through the screen)." (Adrian, male, G4)

Many participants resonate with Adrian's opinion. The narrow field of view and visual clutter of phone screens sometimes might disrupt engagement, forcing players to momentarily disengage from the on-screen AR game world to check their real-world surroundings for safety purposes.

4.3 Verbal Dominance and the Silencing of Gestures

Shared AR introduces a collocated multiplayer experience, differing from participants' previous experiences with online multiplayer games. The need for in-person communication was essential, as players coordinated their movements and collaborated in the shared physical space. As Anthony described, this was a unique aspect of Shared AR compared to traditional online gaming:

> "It is fun and definitely unique. It is unlike playing a multiplayer game online just through a computer screen. We have to be in person in this game, interacting with other players face to face." (Anthony, male, G2)

To facilitate collaboration, we observed that verbal communication became the primary tool. Due to the physical distances and excitement of the game experience, participants often "shouting" to teammates, ensuring that movements and actions in the Shared AR space aligned. As Krish mentioned, over time, players became more comfortable communicating verbally, and collaboration became smoother:

> "In the later rounds, we felt more comfortable calling out, and collaboration became smoother. Maybe at earlier rounds, if someone was in low health, they just searched around and moved to the Defense role without talking too much. But after a few rounds, we found that shouting out for help was more effective." (Krish, male, G3)

However, despite the physical proximity that made gestures, body language, and eye contact intuitively available, video data shows that these non-verbal cues were often overlooked by other teammates. This was mainly due to the visual load imposed by the AR experience, which demanded players' attention to the game elements on the screen most of the time. Selena reflected on how non-verbal communication was initially underutilized:

> "I don't think I would notice this kind of body language in our collaborations as I mostly look at my phone screen. Only when someone raises their voice to ask for something or suggest something will I notice that." (Selena, female, G2)

This suggests that while nonverbal communications (e.g., gestures and eye contact) are intuitive and valuable for collaboration, the visual load of AR experience initially led players to rely more on verbal communication and ignore these nonverbal cues.

4.4 Localization Process as a Collaborative Setup

The localization process in Shared AR was a crucial aspect of gameplay that required collective problem-solving. At the beginning of each round, one teammate (Host) would select a spot in the play area to place the AR anchor (Yeti). The other teammates would then use their device cameras to scan the area and locate the Yeti on their screens. While most participants found the process intuitive, occasional challenges arose, making it a shared task to troubleshoot technical issues, as the game could only begin once all teammates had successfully completed localization.

In ideal conditions, the localization process was swift, typically taking less than a minute. However, disruptions occasionally occurred, such as players moving their devices too quickly or failing to complete a full scan around the Yeti. These issues prevented proper recognition of the AR anchor, resulting in session timeouts and collective frustration. In these moments, players felt unified by a common goal–"We just want the game to start!" (Eli, male, G4)

This necessity for synchronization turned the localization process into a collaborative problem-solving space. Participants quickly adapted to troubleshooting together, with those who finished faster often assisting others–sometimes even holding their teammates' devices to help them. Though players did not always immediately understand why this issue occurred, they gradually developed strategies to optimize the localization process. For example, Group 4 discovered a "sweet spot" where scanning the Yeti was easier. Once one teammate successfully located it, they would guide other teammates to position their devices at the same angle for faster detection. Similarly, Group 2 found that having the Host perform a full 360-degree scan around the Yeti might lower the scanning difficulty for other teammates. Groups 1 and 3 also realized that placing the Yeti in well-lit areas, such as near windows, significantly enhanced scan accuracy.

These strategies were more than just practical solutions—they reflected emergent collaboration. Faced with a shared challenge, players adapted, exchanged insights, and worked together to ensure a smooth start. More importantly, this problem-solving process fostered a sense of camaraderie, even among strangers. As Nathan observed:

> "The localization process shows AR technology's imperfection. But it brings the team together. I know sometimes our ideas wouldn't help or make sense. At least we tried together and helped each other, which was a good feeling—we solved something as a team."(Nathan, male, G1)

Ultimately, what could have been a frustrating technical hurdle transformed into a bonding experience. Through shared effort, communication, and adaptability, players not only improved their localization efficiency but also strengthened their group dynamic. Even among unfamiliar teammates, the necessity to collaborate toward a common goal laid the foundation for deeper engagement and teamwork throughout the game.

4.5 Taking Spatial Aspect into Collaboration Strategies

Unlike the Host assignment, which was random and had no impact on gameplay, game role assignment required group discussion, as it directly influenced both individual experiences and the team's overall performance.

Before each round, teammates gathered to deliberate on role distribution, aiming to maximize their chances of winning. Jacob described how this process unfolded:

> "Before each round, we stood together, and someone would suggest, 'We need this amount of Offense and this amount of Defense.' Maybe someone else says other numbers. After discussion, we all feel happy with one idea eventually. And then, everyone was assigned to a role." (Jacob, male, G4)

Initially, role selection was driven by personal preference, with players choosing "Defense" or "Offense" based on what seemed interesting or what they had not yet tried, rather than considering strategic benefits for the team. Consequently, early discussions were brief, as players focused more on individual experience than team synergy.

However, as the game progressed, all groups recognized the need for balance, ensuring a trade-off between offensive power and sufficient healing. With more experience, players refined their strategy further, incorporating spatial awareness into their role assignments. They began to consider where players should be positioned relative to each other to enhance team coordination.

For example, later in the game, teams paired "Defense" players with "Offense" players in close proximity, ensuring immediate healing in critical moments. This spatially adaptive strategy allowed teams to respond to dynamic challenges more effectively, ensuring that help was always within reach.

As role assignment shifted from personal preference to team-driven decision-making, players often had to compromise their individual choices for the greater good. Jay reflected on this shift:

> "I remember for two rounds, I ended up playing Defense, not because I prefer the role, but because we needed three players to play Offense, and they were already taken… I feel this is part of the teamwork." (Jay, male, G3)

In this way, Shared AR not only encouraged tactical decision-making (balancing roles) but also fostered spatial intelligence in collaboration. Players realized that effective role distribution was not just about having the right numbers but about leveraging spatial positioning to create a synchronized, adaptable, and resilient team. This emergent strategy strengthened team coordination and shared responsibility, as players adapted their roles dynamically based on the spatial and tactical needs of the game.

4.6 Interactions with Non-players: Private Context in Public Play

A notable social dynamic emerged when participants interacted with non-players in shared spaces. Unlike traditional digital games played in public, where bystanders can easily recognize what is happening on a public screen, mobile AR play introduces an "information gap"–non-players share the same physical space but cannot perceive the virtual layer of the game.

This gap influenced how both players and non-players navigated the environment. Participants frequently moved around, gesturing and conversing about AR gameplay elements unseen by others. Non-players, unaware of the digital layer, sometimes walked through active play areas, leading to inevitable interactions. Interestingly, no participants reported non-players' interference disrupting gameplay, rather, these encounters sparked confusion and curiosity from the non-players. Roy described one such moment:

> "It was funny when others (non-players) passed through us, and they would ask what is going on as several people are moving around. I remember I said to one of them, 'Do you realize you're walking through a battlefield?' And he just smiled and had a glance at my screen, very curious about our activity. So that was a nice interaction." (Roy, male, G3)

Participants also recognized that their group interactions made their activity more legible to bystanders. Anthony reflected on how being part of a visibly engaged group made him feel more comfortable in public:

> "Other people could see that we were playing a game together, and we were talking and interacting. If I was the only one holding the phone, I would feel awkward. But we have a context here! And people could tell that. We weren't weird." (Anthony, male, G2)

Here, we observed a unique social ambiguity–AR interactions unfolded in a public space that was visibly active yet contextually invisible to bystanders. Players were fully immersed in the game, gesturing and reacting to virtual elements that non-players could not see.

5 Discussion

In this section, we unpack and discuss our findings against existing research on mobile AR experiences and broader social play. Based on the insights, we also outline design implications for future Shared AR games.

5.1 Spatial Awareness and Movement in Shared AR

Our findings reveal that, in the early rounds, players remained largely stationary while holding their phones, moving less than the game's design affordances suggested. However, as the game progressed, they began navigating the space more dynamically—approaching each other freely and adjusting their phone angles.

The initial hesitation to move can be attributed to players' territorial boundaries, aligning with prior research on collocated multiplayer experiences [66]. As players became more familiar with each other, they grew increasingly comfortable navigating the space, a pattern observed in movement-based games [26, 27]. However, this alone does not fully explain their behavior, as players also did not adjust their phone angles at first. This suggests that they initially perceived Shared AR as a static phone display rather than a dynamic, spatially interactive environment.

Beyond social awareness, spatial awareness emerges as a crucial factor. Unlike conventional screen-based experiences participants usually have, *Urban Legends* introduces a spatially distributed AR environment where the virtual space extends beyond the phone screen. The game world is not centered on any single player but exists in relation to multiple players and the surrounding physical environment. Consequently, movement–both of the player's body and their device–is essential for accessing different perspectives of the AR game space. Yet, we observed that players initially did not recognize the need to move their devices or reposition themselves.

We explain this spatial awareness with Mueller et al.'s exertion framework [44], which conceptualizes bodily engagement in interactive experiences through four lenses: responding, moving, sensing, and relating. In *Urban Legends*, players initially hesitated to respond to the game's spatial affordances. While the game mechanics encouraged movement, players did not immediately recognize mobility as part of the experience. Instead, they engaged with the game in a stationary manner, interacting through verbal communication rather than physical repositioning. Over time, players began moving more actively. The game's mechanics, particularly the healing design (where the "Defense" player must move close to the "Offense" player), encouraged them to navigate the space. This gradual shift highlights how embodied interactions were not instinctively adopted but had to be scaffolded through gameplay. As players moved, their sensing of the game space evolved. Initially, their perception was constrained by the phone screen, as handheld AR does not inherently encourage exploration beyond the visible display. Unlike head-mounted AR, where users' perspectives shift naturally with their gaze, handheld AR requires deliberate effort to adjust device angles and reposition the body [56]. Over time, players learned to actively scan the space with their devices, developing an embodied awareness of AR content in relation to their physical surroundings. The relating aspect emerged as players' movement directly influenced game interactions. As players physically moved within the space, they triggered interactions with other players, which created a sense of connection. This bodily interaction led to a stronger sense of being "in sync" with teammates, enhancing collaboration. As movement became necessary for gameplay, it fostered a deeper connection between players' bodies and their shared environment, keeping players actively engaged with both the game and each other. This movement-driven interaction promoted sustained bodily activity, reinforcing the dynamic nature of Shared AR.

Additionally, players perceived the on-screen AR overlay as visually cluttered, making it difficult to see their physical surroundings. This required them to shift their gaze between the AR display and the real-world environment, introducing an attention negotiation between virtual and physical spaces. While the debate on AR's impact on cognitive load remains ongoing [13, 61], our findings suggest that in phone-based AR, excessive visual content can overwhelm players due to limited screen size. More importantly, clear visibility of the real-world environment is essential for safety, reinforcing the need for design strategies that balance AR engagement with situational awareness.

Building upon these, we present two design implications.

Design Implication 1: Scaffolding Spatially Dynamic Interactions

Shared AR games should actively guide players in understanding and embracing spatially dynamic interactions. Since players may initially perceive Shared AR as a screen-bound experience, design interventions should encourage movement and exploration. Potential solutions can include:

- Device Movement Guidance: Provide contextual instructions to encourage players to explore the game space, such as reminders to adjust their position or reorient their device to reveal more of the AR environment.
- Movement-Based Incentives: Game mechanics that reward movement, such as unlocking new content or improving game outcomes when players physically explore their environment. For instance, the "Healing others at close range" rule in *Urban Legends* exemplifies how movement can be seamlessly integrated as a core gameplay mechanic.

Design Implication 2: Balancing AR Overlays and Real-World Visibility

The visual design of AR experiences should carefully balance digital overlays with real-world visibility to prevent cognitive overload and ensure safety. Players often struggle to process AR content while maintaining awareness of their physical surroundings, especially in phone-based AR with limited screen space. Potential designs can include:

- Transparent or Adaptive AR Overlays: Dynamically adjusting the opacity or density of virtual elements based on player movement or environmental factors to avoid obstructing key real-world details.
- Context-Aware Display Management: Designing AR interfaces that selectively highlight essential information while minimizing visual clutter, ensuring players can balance between the digital and physical worlds.

5.2 Communication and Collaboration in Shared AR

Shared AR gameplay necessitates an integration of spatial coordination and digital interaction that extends beyond traditional movement-based games. Prior research on movement-based games, where bodily movement is either a central game mechanic, such as in dancing games [26], or used to interact with remote screens, like motion-controlled games [45], highlights the importance of physical movement. In Shared AR, however, movement plays an even more integral role. Players must constantly adjust their positioning and device orientation to optimize their field of view, align virtual objects across multiple perspectives, and navigate real-world spatial constraints. This interaction between bodily movement and digital alignment is not a mere byproduct of AR but a core aspect of gameplay that encourages players to develop a shared spatial awareness that extends beyond individual screens. This highlights the communication among players in Shared AR.

We observed that verbal communication plays a dominant role in Shared AR collaboration, while non-verbal cues are being ignored. In traditional multiplayer games, players share a unified game space (e.g., a shared board [66] or a public screen display [26]), which naturally supports mutual awareness. In contrast, Shared AR spatially distributes game elements across individual perspectives, making it more challenging for players to track their teammates' actions. Moreover, as previously mentioned, players' visual attention is largely occupied by their own device screens. As a result, they rely heavily on verbal communication to stay coordinated and remain aware of each other's actions. Meanwhile, non-verbal communication–such as gestures, facial expressions, and eye contact–is crucial for collaboration and has been widely acknowledged in the literature [19, 24]. Our observations reaffirmed this, as participants intuitively attempted to communicate non-verbally. However, we observed that participants' visual attention was overwhelmingly focused on their screens, significantly diminishing these non-verbal cues in the physical surroundings. This finding supports the attentional tunneling effect in AR [50], where users tend to focus too much on the virtual layer (displayed by the phone screen) and ignore the physical surroundings.

Prior research on online games [34] highlights the importance of non-verbal communication in virtual environments, where computer-mediated cues, such as alerts, provide auditory and visual signals that are easy to activate and assist teammates in coordination. In Shared AR, while verbal communication remains an effective coordination method in face-to-face interactions, spatial pointing plays a crucial role in aligning players' spatial understanding [9]. To enhance communication, particularly for spatial directives like "go there" or "come here," integrating non-verbal cues—such as haptic signals—could significantly improve player coordination.

In addition, our observations provide empirical support for the usability issues in SLAM-based marker-less AR noted in prior research [21]. Despite technical imperfections, players adapted through collaborative problem-solving, working together to resolve synchronization and alignment issues in Shared AR. Surprisingly, these challenges transitioned from being individual obstacles to group problem-solving tasks, reinforcing team cohesion.

The public nature of the game introduces an additional layer of interaction with non-players. While prior research has examined bystander interactions in public play [62], Shared AR games—being phone-based—create a unique dynamic where players' physical movements and conversations are visible, but the virtual content remains private. This information gap often sparks curiosity and occasional confusion among bystanders, a phenomenon previously observed in location-based AR games like *Pokémon GO* [11]. Unlike concerns in large-scale location-based AR games, such as trespassing or traffic hazards, *Urban Legends* was played within a campus environment, covering only a corridor-sized space. As a result, it had minimal impact on non-players and did not introduce significant challenges to bystander interactions. This suggests two key considerations for future research: first, exploring Shared AR experiences in more open, public spaces to examine their broader social impact; second, recognizing that the spatial scale of AR experiences likely influences bystander reactions, with smaller-scale implementations potentially being more socially acceptable. Ultimately, this highlights the need for designers to consider the social acceptance of AR activities in public spaces. Understanding and addressing bystanders' curiosity and potential confusion is crucial for fostering inclusive and seamless Shared AR experiences [68].

Design Implication 3: Supporting Peripheral Awareness in Communication

In Shared AR games, where the game environment is experienced individually by each player, peripheral awareness becomes essential for effective collaboration. Since non-verbal cues are harder to perceive in Shared AR, integrating multi-modal cues can facilitate better teamwork.

Potential solutions include:

- Haptic Feedback or On-Screen Notifications: Introduce tactile feedback or subtle notifications on-screen to indicate teammates' movements or actions [39]. For instance, a slight vibration or icon could signal when a teammate is near or performing a collaborative task.
- Audio Spatialization: Implement 3D spatial audio that adjusts based on the position of teammates, allowing players to "hear" each other's actions or directions, enhancing communication without needing to constantly shift visual attention between on and off the screen.

Design Implication 4: Bridging the Information Gap for Non-Players

Shared AR games, played in public spaces, often present challenges for non-players who might observe but not fully understand the ongoing gameplay. Design elements that inform non-players about the AR activities can enhance the social acceptability of these games.

Potential solutions include:

- Public Display for Context Awareness: Incorporate a shared screen in the play area that provides a simplified real-time visualization of the game's key events. This could display abstract representations of player actions, highlight objectives, or show minimal game-related animations, helping bystanders understand what's happening.

- Contextual Cues for Bystander Interaction: Resonate with the guideline in the movement-based game in public [27], future design can consider enabling non-players to engage with the AR experience by providing interactive cues that let them understand what is happening or even allow them to influence the game in non-disruptive ways.

6 Limitations and Future Work

This work has some limitations, which should be considered when interpreting our findings. Firstly, our participant pool consisted entirely of university students, a demographic that may have higher technological literacy than older generations [47, 64]. While this allowed for a focused examination of Shared AR interactions among digitally proficient users, it also resulted in a relatively homogeneous sample. As a result, the extent to which our findings generalize to broader populations remains an open question. Future research should explore how different demographic groups, including older adults and those with less experience in AR, engage with Shared AR. Additionally, studying interactions among acquainted users (e.g., families and friends) may yield insights into how pre-existing relationships shape collaboration in Shared AR. With the advancement of Shared AR technology, examining larger groups (e.g., more than 20 participants) could further reveal how group size influences interaction patterns. While our sample size was reasonable for qualitative inquiry, a broader and more diverse participant pool could provide a richer understanding of Shared AR dynamics.

Secondly, our study focused on Shared AR interactions within a gaming context, which means that caution should be exercised when applying our findings to formal collaborative settings such as the workplace. Although gamified elements are increasingly incorporated into various group activities, structured work environments may involve different dynamics and constraints. Therefore, our findings are most applicable to recreational and hybrid settings where playful collaboration is central. Future research should investigate how Shared AR functions in non-gaming contexts to better understand its broader applicability.

Moreover, our observations were limited to an indoor, campus-based environment and centered exclusively on *Urban Legends*. This setting provided a controlled yet naturalistic space for studying Shared AR, but it may not fully capture the complexities of outdoor interactions, where factors like environmental noise, spatial constraints, and lighting conditions can influence user behavior. While our study offers key insights into Shared AR dynamics, future work should examine different AR applications across varied settings to deepen our understanding of how location and environmental factors shape interaction. Outdoor studies, in particular, could shed light on challenges such as situational visual impairments during mobile interaction [63].

Finally, we explored Shared AR exclusively through mobile phones, which are among the most widely accessible AR platforms. However, other AR devices, such as AR goggles and head-mounted displays, offer distinct affordances that may influence user interactions and social behaviors. While our findings contribute to the understanding of Shared AR in mobile contexts, future research should investigate how different AR hardware affects collaboration, communication, and spatial awareness.

Overall, while these limitations define the scope of our study, they do not diminish its contributions. Instead, they provide a roadmap for future research, highlighting important avenues for expanding the generalizability and applicability of our findings. Readers should interpret this work as offering foundational insights into Shared AR interactions, particularly in mobile gaming contexts, with the understanding that further research is needed to explore its full range of possibilities across different user groups, environments, and technologies.

7 Conclusion

In this study, we used the Shared AR mobile game Urban Legends as a probe, working with four groups (22 users) to explore group interactions and dynamics. Through observations, focus groups, and interviews, we examined how users navigated shared virtual spaces, coordinated actions, and adapted to the interplay between digital and physical environments. While our study is grounded in a gaming context, the interaction patterns we observed—such as spatial awareness, role negotiation, and adaptive communication–extend beyond mobile gaming. Based on these insights, we propose design implications for improving spatial coordination, supporting multi-modal communication, and fostering a wider societal embrace of the Shared AR experience. In conclusion, Shared AR presents a transformative avenue for facilitating enriched social interactions. Our research underscores its emergent potential and paves the way for future investigations into its multifaceted implications for societal engagement.

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A Participants' Demographic Information and Prior AR and Game Experience

	Pseudonym	Gender	Age	Ethnicity/Race	Overall Game Experience	Has Used AR-apps Before
Group 1	Taylor	Male	22	White	hardcore	Yes
	Nathan	Male	19	White	non-gamer	No
	Alex	Male	20	Latino	casual	No
	Jolie	Female	20	White	hardcore	No
	Kai	Male	18	White	casual	No
Group 2	Ivan	Male	18	African American	casual	No
	Kelly	Female	23	Asian	non-gamer	No
	Dana	Female	22	Asian	casual	Yes
	Anthony	Male	18	White	casual	No
	Selena	Female	23	Asian	hardcore	Yes
Group 3	Roy	Male	26	Asian	casual	No
	Casey	Female	25	Asian	casual	No
	Jeffrey	Male	19	White	hardcore	No
	Jay	Male	19	White	casual	Yes
	Krish	Male	18	White	hardcore	No
	Rui	Female	25	Asian	hardcore	Yes
Group 4	Kevin	Male	24	Asian	casual	No
	Jacob	Male	20	White	casual	No
	Rita	Female	34	Asian	casual	Yes
	Adrian	Male	18	White	casual	No
	Ken	Male	20	White	casual	No
	Eli	Male	23	Asian	non-gamer	No

Table 1. Participants' Demographic Information and Prior AR and Game Experience

B Focus Questions

(1) What did you discuss before each round? Did anyone lead the discussion?
(2) How did you decide on the roles? How did that change in different rounds?
(3) How did you communicate in-group during the play? How did that change in different rounds?
(4) How did you interact with non-users in the space? And how did you interact with the environment?
(5) Did you encounter any issues during the process? What was that? How did you resolve them?

C Interview Questions: Urban Legends Game Experience

Would you like to spend approximately 40–60 minutes sharing your playing experience of **Urban Legends** with us? **Yes/No** (Exclude and thank if they say no)

Please let me know at any point if you do not want to answer these questions, and we can skip to the next question. Your personal information will not be disclosed to anyone outside of the research team. You may stop the interview at any time.

Can I audio-record the interview? It is anonymous so please do not take any names during the interview. **Yes/No** (Start recording if yes, ask if you can take notes if no)

1. Social-demographic questions

- What gender do you identify with? (ask for preferred pronoun)
- What is your age?
- Are you an international student?
- Where are you from/race?

2. General gaming questions

- Do you play games, and what are they?
- Have you ever experienced AR products? If yes, what was it? Please describe.
- Do you know about AR LBGs? Did you play any?
- Have you ever played an AR LBG? If yes, what was it?
  - How long and how often do you play them?
  - How do you feel about them?
  - Can those games occupy more than one player? If yes, how do you play together?
  - Who do you play them with? (i.e., friends, family members, strangers)
- If yes, what do you think is the difference between those experiences and Urban Legends? Which is better?

3. Urban Legends playing experiences

- What do you like and dislike about the play experience?
- What is your favorite or most interesting memory while playing the game? Please describe it.
- What is your worst memory (e.g., negative or embarrassing experiences) while playing? Please describe it.
- How do AR components affect your gameplay experience?
- Did you experience any anxiety, stress, or loss of focus during the game? Why or why not?
- What role did you play: Offense or Defense?
  - If you tried both, what are the differences? Regarding gameplay and strategy.
  - If you tried both, which one would you prefer? And why?
- Did you find any of the roles more challenging than the others? Why?
- What are the differences in playing over time?
  - Did you improve your strategy? How?
  - Did you feel tired over time?
- Where did you play the game?

    - As a group, did your (i.e., all players') play area expand or shrink? Why is that?
    - Individually, how did you change your position? How did your teammates and others move around you?
- Do you have any safety concerns or other concerns while playing the game?
- How did you interact with people who did not play the game? What kinds of reactions do you get from people who do not play?
    - What happens if they come to your play area?
    - Do you mind looking at you when you play the game?

4. Social Interactions in a general community: Localization, Coordination, and Collaboration

- Do you understand what localization is?
    - Can you describe the process?
- How do you feel about the localization process?
- How much time did you need to finish the localization during the game?
- Did you feel it took longer or less time for each round when you tried to localize?
- How long did your teammates finish the localization process?
- Did anyone encounter any difficulties in your group during the localization process?
- How do you coordinate the game roles and "first player" within the group?
    - How do you decide who are the Defenses and Offenses? And who is the first player?
    - Is someone leading the process?
- Did you feel dominated by anyone while you were playing the game?
- From your perspective, did you have leadership from the get-go? Or you selected a leader later on? Or did someone spontaneously do that?
    - Why/why not?
    - How did this change the experience?
- While you were playing, did you face any issues because of the people who were in the game space but not in the game? If yes, then what were the issues?
    - Could you solve the issues while you were in the game? If yes, what strategies did you follow to solve the issues? If not, why do you think you couldn't solve it?
    - Did you have to communicate with the people who were not in the game? If yes, how did you communicate with them?
    - Did communicating with people outside the game interrupt your gameplay in any way? If yes, please explain.
- How do you collaborate during the game?
    - Who do you need to communicate with? The same role? The other role?
    - Why do you need to communicate with them?
    - How often do you need to communicate with them?
    - How do you communicate with others? By mouth? Gestures? Any other non-verbal communication?
    - Did the collaboration become smoother and better after the first time playing? Why or why not?
- Have you had any conflicts during the game? How do you manage them?
- How are you aware of your contribution to the team's activities and goals?

5. Perceptions

- Are you willing to play the game again?
- If yes, with strangers, families, or friends? Why?
  - If families, who do you want to play with (e.g., siblings, grandma)?
  - How many people do you want to have? Suppose you are playing with multiple players at a time. Would you want to divide into multiple groups (sessions) of games to compete with each other as teams? And why or why not?
- Where would you want to play this game?
  - Private: indoor home places (e.g., living room), outdoor home places (e.g., backyard, pool, etc.)
  - Public: playground, meadows, parking lot, lobby in a building, etc.
  - Why do you prefer this place?
- When and how often do you want to play the game in your daily routine? E.g., after school, before dinner?
- How do you think you can benefit from playing the game?
- Any issues/challenges you encountered during the whole experience?
- Will you recommend this game to others? Why?