Co-Designing Location-based Games for Broadband Data Collection

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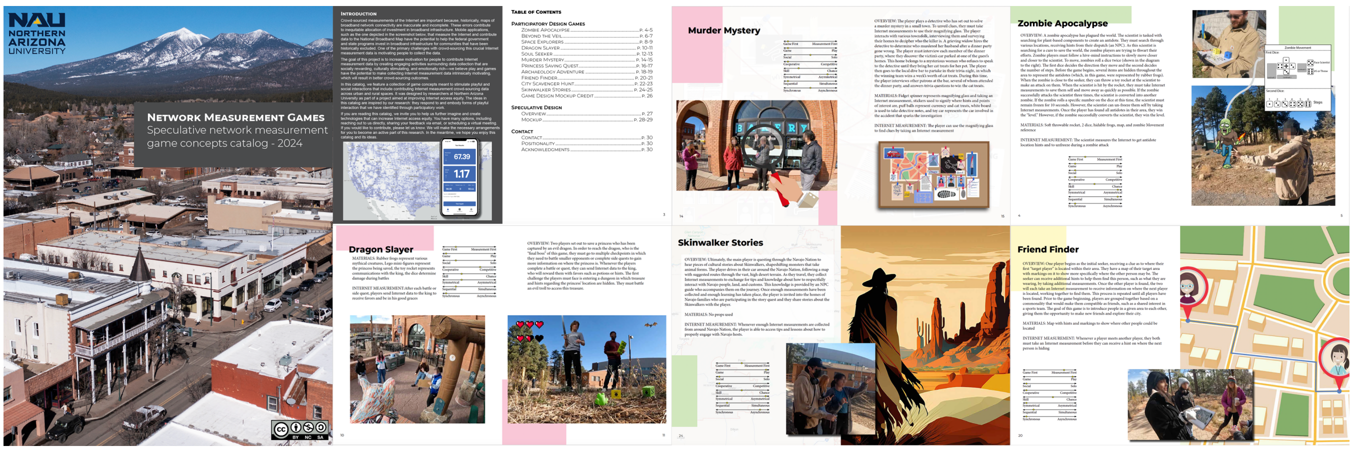


Figure 1: Thumbnail view of selections from network measurement game design concept catalog available at http://tinyurl.com/yd7s7dzk

ABSTRACT

Crowdsourced data collection is a scalable approach to collecting mobile broadband performance data across space. However, existing platforms for crowdsourced mobile broadband measurements are not designed to engage workers over time or space, which can lead to spatial misrepresentation and stale data. With the insight that games and play offer naturally engaging frameworks for users, we held five iterative, participatory design sessions with 11 participants to co-design a catalog of 11 game concepts that could be used to create more spatially representative mobile broadband data sets. Importantly, we found that while games varied substantially with respect to theme, all used a few common game mechanics to incorporate mobile broadband data collection into play. This indicates that a designed prototype might focus on offering a customizable gaming structure that would allow communities and individuals to create thematic content that could overlay onto a set of common mechanics that could support more representative geospatial data collection.

CCS CONCEPTS

• **Networks** → **Network measurement**; • **Human-centered computing** → **Participatory design**; *Computer supported cooperative work*.

KEYWORDS

broadband measurement, mobile broadband, location-based games, serious games, body storming, participatory design, research through design

DIS '24, July 01–05, 2024, IT University of Copenhagen, Denmark

ACM ISBN 979-8-4007-0583-0/24/07
https://doi.org/10.1145/3643834.3661502

ACM Reference Format:
Jared Duval, Shelby Hagemann, Tochukwu Ikwunne, Dayra Quinonez, and Morgan Vigil-Hayes. 2024. Co-Designing Location-based Games for Broadband Data Collection. In *Designing Interactive Systems Conference (DIS '24), July 01–05, 2024, IT University of Copenhagen, Denmark.* ACM, New York, NY, USA, 16 pages. https://doi.org/10.1145/3643834.3661502

1 INTRODUCTION

Bridging digital inequities and enabling emergent 6G applications requires fine-grained information about the availability and performance of mobile broadband (3G/4G/LTE/5G) across space. However, developing and maintaining accurate data about mobile broadband coverage and performance have been significant challenges for the networks research community [42, 73, 74, 86] and comprise many elements of Rittel and Webber's "Wicked Problems" [93]–challenges that are multifaceted and interconnected with no clear solution.

For decades, coverage maps relied on radio propagation models, but several recent studies demonstrated that these maps often overstated mobile broadband availability–aggravating digital inequities [42, 74] and creating a Wicked Problem [22, 52, 93]. To address these challenges in the United States, the US Federal Communications Commission (FCC) recently instantiated the Broadband Data Challenge (BDC) process. Through this process, data collected by citizens with smartphones are used to officially challenge (and fix) the National Broadband Map[1] that is used to determine eligibility for infrastructure subsidization and spectrum licensing. The BDC process assumes that citizens will collect sufficient data from areas most likely to be misrepresented in the National Broadband Map, including rural spaces and tribal communities. However, critical examinations of spatial data collected by crowdsourced efforts tend to underrepresent rural and non-white communities [15, 92, 100].

While several techniques have been explored to incentivize crowdwork in general, the measurement of mobile broadband performance across space presents several unique challenges. Existing broadband measurement tools frame measurement as a dry and technical activity, which can alienate many potential participants. These existing tools also present broadband data collection as an individual activity and they do not fundamentally support coordinated, community-based measurement efforts. Moreover, relying on incidental mobility patterns (such as routine routes from an individual's home to work) can make rigorous data collection challenging in crucial areas. Finally, the evolving nature of mobile broadband infrastructure and technologies necessitates that performance data is continuously collected over time. In this context, games and play emerge as a compelling framework for facilitating crowdsourced mobile broadband data collection. Specifically, games can be designed to be approachable, engaging, and promote specific actions over time and space.

To explore the potential of using games and play to support mobile broadband measurement, we conducted an iterative series of participatory design sessions with 11 participants to investigate how individuals without prior broadband measurement experience envisioned geospatial broadband measurement games. We approached these design sessions with two research questions at the fore:

RQ1: *How do participants integrate mobile broadband measurement into geospatial game concepts?*

RQ2: *What design opportunities emerge to accommodate a range of thematic game interests that support geospatial crowdsourcing?*

This paper makes the following contributions:

- We describe 11 unique game concepts co-designed to promote mobile broadband data collection. In framing mobile broadband measurement as a "Wicked Problem," we analyze each of these games using a research through design (RtD) approach [116] and describe the range of game mechanics used in each. We also examine how participants conceptualized mobile broadband measurement within the context of geospatial gameplay.
- We quantitatively examine how different game concepts lend themselves to movement around space in different types of settings. Across five of the games used for warm-up activities, players covered an average of 415.2m with an average radius of gyration of 17.9 m during a single iteration (approximately 12-15 minutes) of gameplay.
- We propose a speculative design concept that synthesizes and supports the emergent themes and mechanisms that emerged in our design sessions. The resultant "Deck" concept provides a flexible and customizable framework that could support creative appropriation and adaptations that fit different community needs.

The paper is organized as follows: First, we provide background and connections to related work. Next, in Section 3, we describe the methods used to facilitate participatory design sessions and analyze the resulting data. In Section 4, we describe the design of selected games, followed by an analysis of the games in Section 5. In Section 6, we employ our findings by presenting a resulting speculative design. Finally, we discuss our contributions in the context of serious gaming and mobile broadband measurement in Section 7.

2 BACKGROUND & RELATED WORK

In this section, we provide background that contextualizes the importance and challenge of Internet data collection and how it is poised to impact Internet policy and resources in the United States. We then identify related work relating to games and play as frameworks that support sustained engagement of users and then identify specific examples of how serious games have been used to support crowdsourced data collection efforts.

2.1 Broadband Data and Policy

While there have been a number of federal efforts to increase the deployment of broadband infrastructure across the United States over the past decade, anecdotal and empirical data suggest that many communities are persistently excluded from the impacts of these broadband deployment efforts [17, 32, 50, 94]. Even for wireless ICT infrastructure–touted as the method by which the "next billion people" will receive broadband access–critical digital inequities persist [23, 50, 62]. This is particularly the case for mobile broadband networks (i.e., 3G/4G/LTE/5G), where coverage maps that dictate deployment needs have been based on radio propagation models rather than measurements of actual service [36, 38]. Unfortunately, as a growing number of individuals and services come to rely on mobile broadband as their main or sole source

[1]The official map that determines where broadband infrastructure exists in the United States, https://broadbandmap.fcc.gov/home.

of Internet connectivity, discrepancies between projected and actual ICT accessibility can lead to critical gaps in available services for communities [50, 88, 89, 106]. While this paper focuses on the particulars of broadband mapping from a US-centric perspective, there are parallel efforts around the globe that leverage broadband mapping as a means towards achieving digital equity [11, 35, 57]. *Thus, accurate mobile broadband maps are a key step towards digital equity.*

One way to create more accurate mobile broadband maps is through crowdsourced measurement wherein individuals use smartphones to collect broadband performance data using broadband measurement apps [39]. Indeed, the FCC has implemented the BDC process, whereby compliant measurement apps can be used to collect and submit mobile broadband performance measurements to the FCC as part of of a formal challenge to inaccuracies in the National Broadband Map. This is important because the National Broadband Map is used by federal and state programs to determine which communities are eligible for funding to deploy or enhance mobile broadband infrastructure. Other entities, such as the Canadian Internet Registration Authority (CIRA) and the European Commission, have employed similar crowdsourced efforts to better understand broadband infrastructure at scale [35, 57]. Unfortunately, analyses of existing crowdsourced mobile broadband coverage and performance data sets suggest that there is a significant bias in the spatial representation of data produced by crowdsourced measurement efforts [56, 71, 74, 104]. Thus, we identify the first major design challenge for crowdsourced mobile broadband challenge:

Challenge 1: *Tools and platforms for crowdsourcing mobile broadband should explicitly encourage participants to collect data in places that are most likely to be unserved or underserved by existing infrastructure and misrepresented by broadband maps.*

Beyond the challenge of collecting mobile broadband data in misrepresented places, it is important to note that data about broadband infrastructure can quickly become stale. This is particularly true for mobile broadband infrastructure, which can rapidly change depending on radios, antennas, and protocols that are deployed at particular tower sites. Moreover, as demands on particular base stations change with user mobility patterns, it can be challenging to assess whether particular sites are sufficiently provisioned over time. To that end, a second design challenge emerges:

Challenge 2: *Tools and platforms for crowdsourcing mobile broadband should engage sustained participation (on the order of months and years) to adequately capture changes to infrastructure performance over time.*

In the following sections, we will examine how game and play emerge as promising frameworks for addressing these challenges and we discuss how other crowdsourced data collection efforts have leveraged serious games.

2.2 Games & Play as Engaging Frameworks

Numerous studies and scholarly works substantiate that games and play are invaluable tools for transforming serious or mundane activities into engaging and enjoyable experiences [19, 29, 30, 72, 98, 101, 111]. This idea of games and play is based on the fundamental understanding that all humans, regardless of age or background, have an innate inclination towards playfulness and a desire for novel, stimulating experiences [99], which also has various cognitive, emotional, and social benefits. [25]. In the field of health, serious games have been recognized for their effectiveness in promoting positive behavioral change [18, 69, 109] and improved health outcomes [29, 30, 48, 51, 78, 90, 91, 110]. The benefits of incorporating games and play extend to the corporate environment (e.g., [7]), in productivity, and in task management [54]. In the field of education, gamification has gained prominence [85, 97], with an emphasis on points, badges, and leaderboards [27]. However, while gamification may initially improve user engagement, it may not necessarily result in long-term behavior change or significant outcomes [108]. As a result, this work emphasizes a deeper engagement with design inspired by playification [84] and situated play design [3, 5, 6, 31]. The use of games and play to address the two challenges highlighted in Section 2.1 is described as follows:

2.2.1 Encouraging Participation over Space. To address the first challenge in Section 2.1, there are several ways that gameful approaches can encourage participants to move around space. Incentivized exploration games offer rewards and recognition for exploring and collecting data in uninspected areas [66]. Several works [44, 77, 80, 87, 112], have contributed to the understanding of how mobility, territoriality, and spatial perception intersect in the context of location-based mobile games. For instance, [87] explored the dynamics of human movement in urban environments through the lens of location-based mobile games. In addition, research has explored play potentials [3] in urban environments that imagine how play can improve navigating future cities [4], which can impact users' understanding of their surroundings [112]. Game location design impacts players' socio-spatial behavior and mobility perceptions within the gaming environment [80], as exemplified by Foursquare [44]. Another approach that could address the first challenge is the gamification of geographical information systems that demonstrate the integration of game elements into mapping [46]. A notable illustration of this approach is evident in popular location-based augmented reality mobile games like Pokémon Go, where gaming activities contribute to the acquisition of valuable geographic information for mapping purposes [8]. This strategy leverages geocaching-style activities to make data collection in underserved areas a compelling treasure hunt, merging discovery with enhancing mobile broadband data. It offers insights into designing location-based games that engage users in exploring and interacting with physical spaces playfully.

2.2.2 Encouraging Participation over Time. There are multiple strategies for engaging participation for sustained periods, including seasonal campaigns and events that can keep content fresh by giving participants reasons to return on a regular basis using progressive storylines and narratives for sustained infrastructure monitoring [9]. Another strategy is providing participants with real-world impact updates that discuss the impact of participating (e.g., [26]). This principle can be applied to mobile broadband data collection, emphasizing the importance of identifying underserved areas in order to achieve tangible, positive results. Gamification can merge exploration, collaboration, and real-world impact with geocaching and community missions to boost data collection and infrastructure monitoring sustainably in underserved areas.

2.3 Serious Games for Crowdsourced Data Collection

Crowdsourcing harnesses communities' collective intelligence and capabilities, promoting democratization of power [59], novel approaches, and innovative solutions [20]. Serious games have emerged as effective tools in supporting crowdsourced data collection efforts, providing engaging platforms that motivate users to contribute valuable information (e.g., [40, 55, 67, 68, 79, 113, 114]) and innovative contributions to science (e.g.,[24, 65, 70]). One notable example is Geo-Wiki introduced by Fritz et al. [45], a serious game that facilitates the validation and improvement of global land cover maps. Building upon this, Tinati et al. [102] conducted an investigation into EyeWire, examining how gamification principles contribute to sustained participation in the citizen science project. These examples underscore the versatility and impact of serious games in supporting crowdsourced data collection efforts across diverse domains and over sustained periods.

3 DESIGN METHODOLOGIES

The significance of the challenges described in the Background Section that this work intends to address meets all ten properties of a Wicked Problem [22, 52, 93] and is, therefore, an appropriate candidate for applying Research through Design (RtD) methodologies and approaches [41, 47, 107, 116]. The specific design research methods we leveraged for this work include participatory design, [81] bodystorming [75], and situated play design [5, 6].

3.0.1 Participatory Design. Participatory Design (PD) originated as a political movement aimed at improving workers' quality of life in the workplace [14]. PD is currently employed in many areas of design [53], ranging from service design (e.g.,[58]) to Human-Computer Interaction (e.g., [81]) or social design (e.g., [16, 34]). Although PD is not a dominant approach in game design [95], some designers have leveraged PD methods to design games [21] that better respond to their players' needs, such as serious games revolved around numerous mental health conditions [95]. There are many PD frameworks [21] that are useful in organizing methods, approaches, techniques, tools, and toolkits [96]. Of special importance is the framework utilized by Ellis and Kurniawan [33]. This framework is useful for our work because it is broad enough to apply to the domain of Serious Games while forcing us to think about the populations we are designing with and providing enough structure for time-efficient co-design sessions. The framework proposes six guidelines, or steps, to conduct PD sessions, including *building bridges*, *developing a user model*, *mapping possibilities*, *developing prototypes*, *eliciting feedback*, and *implementing changes*. The structure of these sessions is described in Section 3.6 with the six above steps appearing in parenthesis.

3.0.2 Bodystorming. *Bodystorming* has been used in HCI to design activities that involve the body and contextual elements [60, 75, 103]. Bodystorming encompasses multiple strategies, including *embodied storming* (a pre-ideation sensitizing activity involving engaging with users' situations and actions), *use case theatre* (using props and having actors as "live personas" to enact relevant situations), and *strong prototyping*, which involves replicating the environment where a design will be deployed with a more or less degree of fidelity to evaluate design concepts [75]. In this work, we employ *participatory embodied sketching*, which involves engaging with end-users and props to explore, test, and iterate future designs for games that crowd-source broadband measurements [75, 82]. Our approach uses a mix of free exploration with existing design concepts at various levels of fidelity (often supported with simulation techniques like Wizard of Oz [28], enactment, and pretense engagement) and guided activities to test existing concepts and prototypes for iteration.

3.0.3 Situated Play Design. Situated Play Design (SPD) is a methodology extending beyond traditional participatory design and play design frameworks, aimed at empowering designers to identify and understand the natural emergence of playful dynamics within various contexts to enhance and support them through design [3, 5, 6, 31]. SPD focuses on designing playful interventions for everyday, non-entertainment-based activities, such as broadband measurement, blurring the line between real-world activities and the realm of play by capturing play's emergence in semi-naturalistic settings [6]. This approach is grounded in observation and support of playfulness that emerges naturally during user interaction, is contextually rooted, and is integrated early in the design process, aiming to address people's social and emotional needs through technology design. SPD is articulated through a three-phase iterative process—*chasing*, *enhancing*, and *deploying* play—with case studies illustrating its application and a discussion on its novelty, challenges, and opportunities [3, 31]. In this paper, we present the first two SPD phases through our bodystorming protocol that *chases the play* and our speculative design presented in Section 6 that *enhances the play.* After developing the application for future work, we plan to *deploy the play* to evaluate its effectiveness and serious efficacy, iterating on the design as needed.

3.1 Data Collection

Before beginning our bodystorming activities, we asked participants to complete brief surveys to collect demographic information. Due to the active and constant movement and discussion involved in our focus groups, we video-recorded each design session using at least one GoPro per participant in the session to support activities where participants spatially separated from each other. By collecting data via video recording, we were able to keep track of comments made by participants, the props they used, and their actions while still being able to be actively involved in the gameplay ourselves. After ideating through a concept, we held short debrief sessions with participants. During this debrief, we asked the lead designer to summarize the premise and rules of their game as if they were speaking to someone who had never heard of it before. Then, we would ask the group of participants open-ended questions to further assess their perceptions of the game. Finally, to collect mobility data we used MapMyTracks[2], an iPhone app that collects GPS coordinates every second.

[2] https://www.mapmytracks.com/

3.2 Data Analysis

We developed a survey that would allow the researchers to characterize each game along eight different dimensions: *Game First* vs. *Measurement First*; *Game* vs. *Play*; *Social* vs. *Solo*; *Cooperative* vs. *Competitive*; *Skill* vs. *Chance*; *Symmetrical* vs. *Asymmetrical*; and *Synchronous* vs. *Asynchronous* (we define the endpoints of these dimensions in depth in Section 5.2). These categories were developed from an emergent design research model for serious games [31]. Each of these categories was evaluated on a five-point scale anchored with their respective endpoints. Employing the model to map the design space contributed to the further iteration of the model, which is a larger research through design project [31]. Using this survey allowed the researchers to systematically compare the different games with each other to see if common characteristics emerged that provided clear answers to our research questions.

To analyze the design sessions, two researchers watched session recordings, noting when new game mechanics were introduced when interesting comments were made by participants, and taking screenshots of the videos where image collection could be useful. For each game, the researchers also completed the game classification survey independently from each other. Once game classification surveys had been completed by both researchers for each of the games, we performed an inter-rater reliability (IRR) analysis on the results using Crohnbach's alpha. Upon performing the IRR analysis on the resulting game classifications after the first round of review, we found that, despite the answers appearing to have high similarity, the rating was lower than what we had anticipated, at 0.67. To determine the underlying cause, we performed the IRR analysis for each game and question individually, making note of which resulted in the highest variability. We then found that the answers between the two researchers classifying the games for "Symmetrical vs. Asymmetrical" and "Synchronous vs. Asynchronous" had the highest variability, significantly skewing the resulting values of the analysis. Upon performing the IRR analysis on the entire dataset without the answers from these two questions, the rating was significantly higher and closer to what we had anticipated, at 0.778. As a team, we discussed how each of these anchor points should be defined in more detail, and the two researchers independently re-classified each game using the survey. Afterward, the IRR analysis results were higher, with a value of 0.81. We examined mobility data collected during the play of warm-up games using descriptive statistical analysis of a variety of mobility metrics, including total route length and radius of gyration [49].

3.3 Design Materials

We provided a range of physical props and materials for each design session, curated to enable a range of affordances related to chance, roles, communication, process, social interaction, spatial annotation, spatial representation, and physical sensations (Figure 2 depicts props used). Some examples of props include low-fidelity and high-fidelity paper maps inserted into plastic protective sheets that could be annotated with dry-erase markers, large foam dice, foam finger rockets, a fidget spinner, small dry erase boards, ping pong balls, laser pointer, and small Lego bricks. A full inventory of our design materials can be found in the Supplemental Materials.

We also provided the participants with several card decks to help facilitate ideation around game mechanics, including an action deck, a challenge deck, and a level-up deck. Action cards corresponded to key actions participants needed to represent in their game design, such as finding the place where measurement needed to be collected and submitting a measurement result. Challenge cards prompted participants to consider mechanisms that might add friction and make gameplay more challenging. Finally, level-up cards prompted participants to consider ways that players might gain new abilities or increase their skill within the game. Materials were presented to participants in two baskets with a full inventory list so they would have an overview of materials at a glance without having to dig through the baskets.

3.4 Sites

In order to emulate different types of places where mobile broadband measurement would need to take place, we organized our design sessions to take place at three different sites, all of which were naturally constrained to a total area of about $30m^2$. Our intent in selecting different types of sites was to help participants consider some of the challenges and affordances that different types of places provided to games. Figure 3 provides an aerial view of each of the three sites.

Campus Site. This site was located outdoors at the NAU campus between several academic buildings. Given our location, there are numerous pine trees and while the site had significant paving, there were also unpaved, uneven areas adjacent to buildings. This space generally observes moderate pedestrian traffic depending on time of day.

Urban Site. To emulate how a game might work in an urban space, this site was located at the heart of downtown Flagstaff. This site was characterized by a built environment, with dense access to sidewalks, benches, storefronts, and parking. This space is generally highly trafficked during the day.

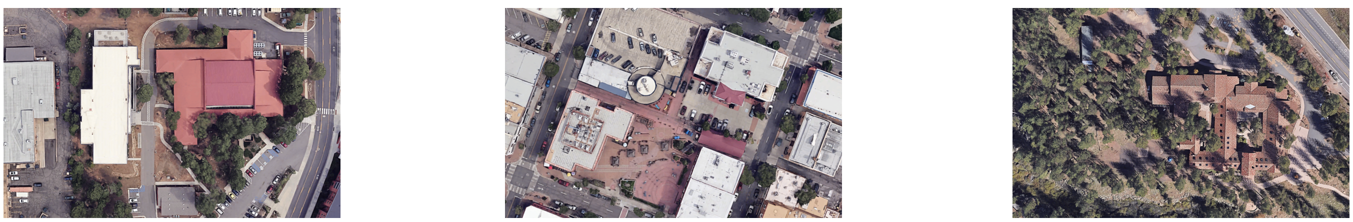
Rural Site. We emulated a rural space with a site located on the outskirts of Flagstaff. This space was a contrast to the other spaces in that it was limited in terms of built infrastructure (there was only one urban trail running alongside the highway), its proximity to the adjacent National Forest, and the distance between places connected by the trail.

3.5 Participants

We recruited participants by sending emails to class listservs and student organizations as well as by posting recruitment flyers at the two branches of the public library in Flagstaff. Our only inclusion requirement was that participants be 18 years of age or older, and we explicitly communicated that no prior game design or network measurement experience was required. As part of our recruitment strategy, we provided potential participants with a sign-up sheet where they could select sessions (time and site) based on their convenience.

Overall, we had 11 participants in our study. We provide an overview of these participants and the site where they ideated their games here:

Figure 2: Materials used in design sessions.



(a) (b) (c)

Figure 3: We facilitated design sessions at three sites, (a) a campus site, (b) an urban site, and (c) a rural site.

Table 1: Overview of participants. Participants are coded to indicate which session they participated in (A-E).

Code	Participant Description	Site
A1	21-year old Native American female	Campus
A2	19-year old Native American male	Campus
B1	19-year old White male	Campus
B2	23-year old Asian male	Campus
C1	20-year old White female	Urban
C2	18-year old White non-binary	Urban
D1	20-year old White female	Urban
D2	20-year old Hispanic male	Urban
D3	25-year old White male	Urban
E1	18-year old Hispanic female	Rural
E2	19-year old Asian female	Rural

3.6 Structure of Game Design Sessions

Design sessions took place in three major parts facilitated by two researchers and recorded in various ways by three other researchers. Each design session was 120 minutes. We describe the structure of sessions here, using parenthetical notation to draw connections to PD guidelines that we integrated from Section 3.0.1.

Part 1 involved the facilitator using 5-10 minutes describing the need for continuous collection of crowdsourced broadband measurements and demonstrating how existing broadband measurement apps look and work, including a description of the meaning of different network metrics such as download speed, upload speed, latency, jitter, and packet loss[37] (*Building bridges*). In this part of the session, participants were given the opportunity to clarify their understanding of the serious goal of the game they would be designing (*Developing a user model*).

Participants then circled up for a warm-up activity that involved participants mirroring each other's movements with music to help create group synergy and a mutual sense of fun (*Mapping possibilities*). Warm-up activities are important because they prepare bodies for bodystorming, create group cohesion, and their silliness helps prime creative mindsets [83]. We then described a game that the previous design group had ideated and shared the props used to enact the game. The participants were asked to play the game together for 20-30 minutes, acting out different roles and actions as described in the catalog (*Mapping possibilities*).

Part 2 began once the participants had reached a clear outcome on the warm-up game. At this point, one participant was selected to identify a new theme that could be used for a new game (*Mapping possibilities*). The only restriction was that the theme could not be repeated in the game created by the previous group. In case participants felt "stuck" when asked to identify a theme, we provided them with idea prompts in the form of two jars containing pre-written *theme* and *value* prompts [43, 115], respectively. Some theme prompts included "nature" and "aliens"; some value prompts [43, 115] were "generosity" and "competition." We provide a full list of theme and value prompts in our Supplemental Material. After a theme had been established, the participant was asked to draw action prompt cards and consider how they might use the material props and the site to thematically implement the action with their fellow participants(*Developping prototypes*). Participants switched roles as necessary or took turns acting out the lead player role to garner multiple perspectives on each prototype (*Eliciting feedback*). We iterated this process through all the action cards. Once a game flow was established to get through basic actions, we introduced the challenge and level-up cards into gameplay, asking the lead participant to consider how these elements might alter gameplay or mechanics (*Implementing changes*). We then repeated this process for each participant in turn, ensuring that each participant had the opportunity to lead the ideation of a game (*Eliciting feedback*).

Part 3 took place after each participant had a chance to ideate through a game concept. We started the final phase by having participants form a circle. We then went round-robin and asked each participant to summarize the game they had created. We then went round-robin in the opposite direction to ask each participant what they liked best about their game idea. We ended by randomly selecting participants to share what they liked best about the game idea that one of the other participants had ideated. We ended by asking participants if they had any questions for us and by informing the participants that we would be synthesizing their ideas with the ideas from others to implement a software version of a game that would help make broadband measurement more engaging.

3.7 Ethical Considerations

Our protocols were reviewed and approved by NAU IRB. Participants were compensated with a $25 Amazon gift card and a certificate of participation. In addition, we provided snacks and drinks to participants in recognition of the time and energy required to participate. We also wanted to try to ensure that our design sites were accessible to as many potential participants as possible. Thus, we ensured that all sites were accessible via public transportation and would be generally accessible in case of restricted mobility.

3.8 Statement of Positionality

Given that the positionality and presentation of design facilitators fundamentally impact the social dynamics of participatory design, we take space here to describe our positionality. The design sessions were facilitated by Vigil-Hayes, Duval (both faculty), and Hagemann (graduate student). Vigil-Hayes has over a decade of experience conducting research characterizing digital disparities and critical design that addresses digital inequities experienced by rural and Indigenous communities. Duval has over seven years of experience leading research around serious games using participatory approaches. Two of the team members identify as male, and three identify as female, and we embrace an intersectional feminist approach to design.

4 DESIGN

We designed a total of 11 games across one pilot session and five participatory design sessions. We describe each of the games in detail in the game catalog included in the Supplemental Material in case others would like to replicate them.

4.1 Pilot

Before engaging with actual participants, the research team engaged in a pilot iteration of a design session, which resulted in two games: *Zombie Apocalypse* and *Soul Seeker*. We briefly describe *Zombie Apocalypse* here and provide an extended description of both games in the Design Catalog in the Supplemental Materials.

Zombie Apocalypse is set in a world overrun by a disease that transforms people into zombies. Players can choose roles such as a researcher seeking genetic clues for a cure or a zombie attempting to stop the researcher. A non-playing dispatcher provides maps to guide the researcher to areas for clues. The game encourages collecting broadband measurements, enabling characters to level up with abilities like teleportation or receiving hints for clues. A game round concludes when the researcher finds enough clues or is infected by the zombie.

4.2 Selected Game Summaries

Here we briefly describe a selection of representative co-designed games. We include a more substantial description of all eleven games in the Game Catalog[3].

4.2.1 Space Explorers. In this collaborative game created at the campus site, players become astronauts who travel between planets to collect resources, exchanging them for mobile broadband measurements. Navigation is guided by dispatches directing them to new planets, where gathering more measurements unlocks additional hints. As astronauts journey, spaceship fuel depletes, requiring fuel purchases at space shops with currency earned from selling resources or completing missions for non-player characters, like repairing ships. Players face threats from rival spaceships or aliens, necessitating weapons and defenses to protect their spacecraft and resources.

4.2.2 Beyond the Veil. In this solo game created at the urban site, the player is a scholar of the ancient literature and lore surrounding the Fae−magical, folkloric creatures. To help cure their loved one of a mysterious illness, they enter the world of Fae through a portal to find a healing herb. As the player searches through the Land of Fae for this magical herb, they encounter a variety of nefarious fairies (NPCs) who wish to harm and distract them. The player must navigate through these challenges by completing side quests, refusing and avoiding tricks by other fairies, and trading goods or completing tasks for further directions to the herb. As the player encounters these puzzles and challenges, they can collect mobile broadband measurements in exchange for hints.

4.2.3 Friend Finder. In this social game created at the rural site, players must collect broadband measurements in exchange for the next clue in a treasure hunt that brings them closer to meeting a new set of friends (other players) at a final rendezvous point.

[3] http://tinyurl.com/yd7s7dzk

The ultimate goal of the game is to engage in a fun activity that results in meeting new people and perhaps getting to know a new community better. It was designed for play at the scale of a city suburb or downtown area. The game ends when all players have found and met each other.

5 FINDINGS

Here we examine video recordings and geolocation records associated with design sessions. For more substantial details about each of the 11 games we conceptualized, we encourage readers to see our Game Catalog in the Supplemental Materials.

5.1 Integration of Mobile Broadband Measurement (*RQ1*)

Across all game concepts, participants integrated mobile broadband measurement activity in only three ways. Notably, only one of the games (*Archaeology Adventure*) gave semantic value to the value associated with collected measurements, e.g., measuring a download speed of 1 Mbps did had a different impact on game play than measuring a download speed of 100 Mbps. As described by the participant who led the design of *Archaelogy Adventure*: *"The main thing is the disparity between the [mapped] score and the score actually being measured...If you get more disparity it means more rare treasure and it's your goal to find those disparities"* (D2). Thus, the value of measured performance metrics were proportional to the disparity between existing broadband maps and the collected data.

The majority (10) game concepts only integrated the action of measurement and used this action in the following ways:

Measurement as Modifier. Five games used the act of collecting a measurement as a way to modify the difficulty of the game. For instance, in the *Zombie Apocalypse* game, the researcher might get clues about the specific location of the data they were searching for by collecting measurements. In *Beyond the Veil*, a player could collect measurements in exchange for hints about how to answer fairy riddles or solve puzzles. *Dragon Slayer* used measurement as a way of increasing the probability of receiving a random "power-up". This was accomplished by allowing players to collect measurements outside of the context of victory conditions and then using the number of measurements collected to act as a probability modifier as to whether they received a "healing potion" or "double damage" abilities to aid them in the next dungeon.

Measurement for Resource Management. Four games used measurement as a way to support players in replenishing resources. In several games, such as *Space Explorers*, movement around space used up fuel resources: *"When you are in dire situations where you can't find any resources to fill your fuel, you have to wait there and send your coordinates [through an internet measurement] from where you are coming [from] to get a little bit of fuel"* (A1).

Measurement as Victory Condition. Five games used measurement as a victory condition–either for the game overall or for a particular level of the game. In *Soul Seeker*, players had to collect a specific number of measurements across specific locations in order to complete a level. *Dragon Slayer* combined both victory conditions and modifiers, where measurements had to be collected at the end of each dungeon to inform the player about the location of the next dungeon, but they also functioned as modifiers.

5.2 Common Game Themes & Mechanics (*RQ2*)

While there was a great variety of themes that we explored in design sessions, many of the games revolved around the concept of questing, e.g., questing to explore planets, save a princess, or find fairy artifacts. There were also a variety of mechanics that were incorporated into game concepts, which we characterized along eight different categories (as shown in Figure 4). Indeed, each of these categories represents a spectrum that ranges between two endpoints on a five-point scale. We display how two researchers on our team scored the games in aggregate with respect to the eight categories in Figure 4 and we describe the endpoints here.

5.2.1 *Game First vs. Measurement First.*

When a game is *Game First*, it revolves around play or narrative. The practice of collecting broadband measurements is incorporated into the game as an afterthought, where mechanics are already created or ideated and the process of collecting data is added in later. Conversely, if a game is *Measurement First* the goal of taking internet measurements is the focus of the game during ideation and action, basing many or all of the mechanics around collecting measurements. The majority of game concepts we generated were *Game First*. For instance, *Murder Mystery* oriented primarily around a murder mystery narrative and it could theoretically be played without collecting any measurements. However, games like *Archaeology Adventure* (see Supplemental Material) required players to collect measurements to take almost any action within the game, and the actual values that were collected informed game actions and outcomes.

5.2.2 *Game vs. Play.*

A game that possesses more *Game* attributes over *Play* attributes has more structure and rules on the paidia-ludus spectrum [12]. Games such as *Zombie Apocalypse* and *Dragon Slayer* had clear victory conditions, rules, and mechanics. Conversely, *Skinwalker Stories* (see Supplemental Material) focused on engaging players with the experience of place and culture with no explicit concept of winning, losing, or rules.

5.2.3 *Social vs. Solo.*

A game that is more *Social* involves collaboration and communication between multiple players (human or NPC). A game that is more *Solo* allows one player to be fully independent during play without requiring interaction with other players. The majority of our games were designed to allow flexibility between social and solo experiences. For instance, *Dragon Slayer* represented a game that could be adapted to be more or less social depending on whether players wanted to band together as a team to take on dungeons or play in a more independent solo mode.

5.2.4 *Cooperative vs. Competitive.*

A game that is more *Cooperative* if it involves multiple players working together to achieve a common goal, where "winning" or "losing" typically occurs collectively. A more "Competitive" game requires some level of incentive for players to perform to a certain level, aiming to achieve a task over others involved in the game. Similar to the *Social* vs. *Solo* category, many of our games spanned this category or incorporated both endpoints into play. For instance, *Zombie Apocalypse* included a competitive relationship between the zombie player(s) and the

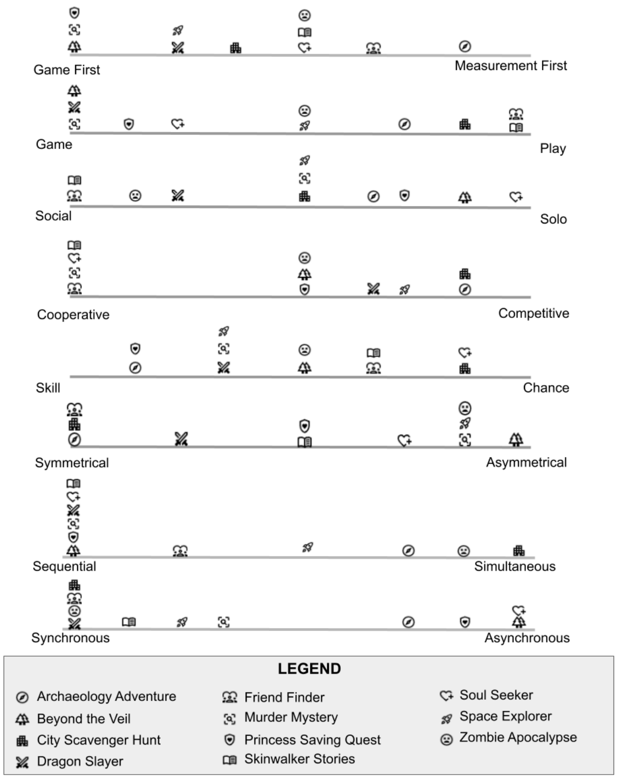


Figure 4: Games rated along each classification spectrum.

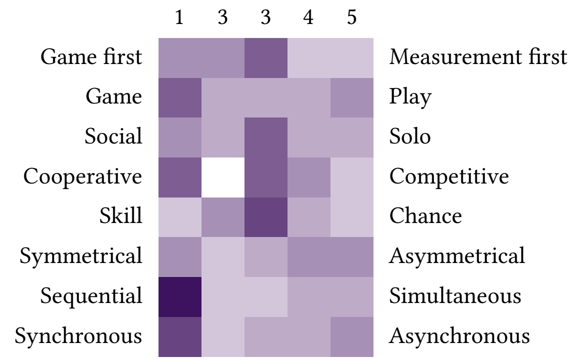


Table 2: Frequency of ratings along each categorical spectrum. (Darkest=12; Lightest=0)

researchers who were looking for a cure, but it also involved cooperation between the researcher and dispatcher players as they sought to locate pieces of the cure to win the game.

5.2.5 Skill vs. Chance. A game that is more oriented around *Skill* involves tasks that players can get better at over time, either by developing real-life skills applicable to the game or by "leveling up" through game experience to improve their abilities in play. A game that is oriented around *Chance* does not require a player to be familiar with game mechanics to increase their chances of doing well and generally provides even odds to all players in their capabilities of performing well. As indicated in Table 2, most games blended elements of skill and chance. For instance, in *Beyond the Veil*, players would be presented with riddles to answer to progress in the game, but there were also options where they could roll dice to determine whether or not to proceed past a challenge.

5.2.6 Symmetrical vs. Asymmetrical. A game that is more *Symmetrical* offers similar roles and power to all players involved in the game, whereas a game that is more *Asymmetrical* has a power imbalance or different tasks distributed among players. Compared to other categories, most games in our catalog tended to orient more towards the endpoints of this category rather than blending elements. For example, *Zombie Apocalypse* is asymmetrical because the researcher, zombie, and dispatcher have different rule sets and objectives, while *City Scavenger Hunt* is an example of a symmetrical game because all players have the same rules and are racing to find the most targets.

5.2.7 Sequential vs. Simultaneous. *Sequential* games incorporate components and revelations that players must unveil through gameplay in a particular order. These games often have a storyline to which players must adhere, moving through predefined steps towards completion. A game that is *Simultaneous* allows players to complete tasks with more freedom regarding order, not necessarily needing to follow a specific direction to unveil more of the game. A sequential game was *Beyond the Veil*, where the main player had to adhere to a predefined path (and preset challenges) or else lose the game. *Soul Seeker* was an example of a game that was more simultaneous–players could mobilize to any of the points of interest where soul shards were located and uncovering any of those pieces would advance the game.

Another way of looking at the distinction in multiplayer games is a turn-based game like *Dragon Slayer* or *Chess* and a non-turn-based game like *Zombie Apocalypse* or *Mario Kart*.

5.2.8 Synchronous vs. Asynchronous. A game that is *Synchronous* requires multiple people to play the game at the same time in the same place, whereas an *Asynchronous* game allows players to leave and come back at later times, not necessarily impacting the gameplay or other players involved. *Friend Finder* was a synchronous game that required players to be in the same approximate area at the same time in order to ultimately find each other and meet up in-person. Conversely, *Beyond the Veil* only required the player to be in a particular place to play; they could leave and return to gameplay without consequence.

Overall, we provide a heatmap of how two members of the research rated all games in Table 2 to more clearly demonstrate how the game concepts holistically represented various game and play mechanisms.

5.3 Impact on Mobility (*RQ1* & *RQ2*)

We tracked the GPS route of players while they played warm-up games during each session. We report on the route length, the

Game	Site	Route Length (m)	Radius of Gyration (m)	Avg. Speed (km/hr)	# Measurements Collected
Zombie Apocalypse	Campus	499	15.54	2.90	5
Space Explorers	Campus	322	23.73	2.54	2
Dragon Slayer	Urban	579	16.55	3.22	1
Beyond the Veil	Urban	354	16.50	2.90	3
Murder Mystery	Rural	322	16.94	1.93	5

Table 3: Overview of spatial mobility characteristics for each of the warm up games.

Figure 5: Photo from our design session at the rural site.

average rate of player speed along the route, and the number of mobile broadband measurements the players collected over the course of the game in Table 3. Additionally, to provide a holistic metric of players' mobility, we measured the radius of gyration. The radius of gyration has been used extensively as a metric of mobility in wireless networks and helps characterize dispersion through space [49]. The radius of gyration is calculated with Equation 1

$$r_g(t) = \sqrt{\frac{1}{n_c(t)} \sum_{i=1}^{n_c} (r_i - r_c m)^2} \quad (1)$$

where r_i represents the the ith coordinate for a player, $r_c m$ represents the center-mass (or centroid) for that player, and $n_c(t)$ represents the number of geocoordinates recorded up to time t. In other words, the greater the radius of gyration for a player during a game, the more dispersed their movements are through space. As shown in Table 3, the radius of gyration measurements and route length varied among the games played and the two did not necessarily correspond. We discuss some potential reasons for this in Section 7.3.

We also note that there was not necessarily a correlation between mobility metrics and the number of measurements collected. Players collected the smallest number of measurements at the urban site on average. At the rural and campus sites, players tended to collect more measurements. Because our final design session took place at the rural site and we were only able to conduct one session at the rural site due to inclement weather, we were not able to have participants play a game designed in a rural site for a warm-up.

However, in the process of designing games in the rural site (*Friend Finder* and *City Scavenger Hunt*), we noted that participants used up significantly more space to try out their game concepts than they did in the urban and campus sites. This is exemplified visually in Figure 5, where participants were significantly spread out as they moved through space to bodystorm. We discuss the intersection of site, game concept, and game play in Sections 7.1 and 7.3.3.

6 SPECULATIVE DESIGN

The speculative design [10] in Figure 6 draws inspiration from each of the design concepts, themes, and mechanics contributed by our participants in the participatory design workshops [81]. To embrace the diversity of the themes, we developed a "Deck" paradigm, where each game from our participants could be accommodated within a single mobile application that hosts multiple "Decks." This paradigm takes its cue from HyperCard's remarkable versatility and its historical significance in the early video game industry, notably in games like Myst. We imagine Twine, a modern descendant of HyperCard and a free tool for creating interactive, non-linear hypertext narratives, would support each theme and experience designed by our participants, so we aim to leverage it as the underlying framework for the app. This approach offers two advantages. Firstly, Twine's structures are flexible and relatively easy to implement for future users to contribute to new "Decks," facilitating future crowdsourcing of both broadband measurement data and game content without the need for researcher involvement, as a sustainable community-based framework [64]. Secondly, Twine's design empowers players by offering multiple pathways through links. We envision that players will utilize the "Decks" for structured gameplay while engaging in role-playing to forge immersive social experiences across various geographies and contexts, akin to Live-Action Role Playing (LARPing). The specific mechanics unique to each game can be outlined in the decks, where players can manage these elements outside of the technology. We anticipate that these "Decks" will strike a balance between providing structured play and allowing for creative appropriation and adaptation similar to the benefits of design probes [76].

To align with the serious objectives of these games, we have conceptualized two key mechanics to be integrated into our app, extending beyond the Twine "Decks." The first is the incorporation of a broadband measurement feature within the Twine nodes. This feature will utilize the APIs of FCC-compliant measurement tools to measure broadband metrics like upload and download speeds, latency, jitter at particular locations. These metrics will be accessible within the "Decks" and can be tied to game outcomes (e.g., links

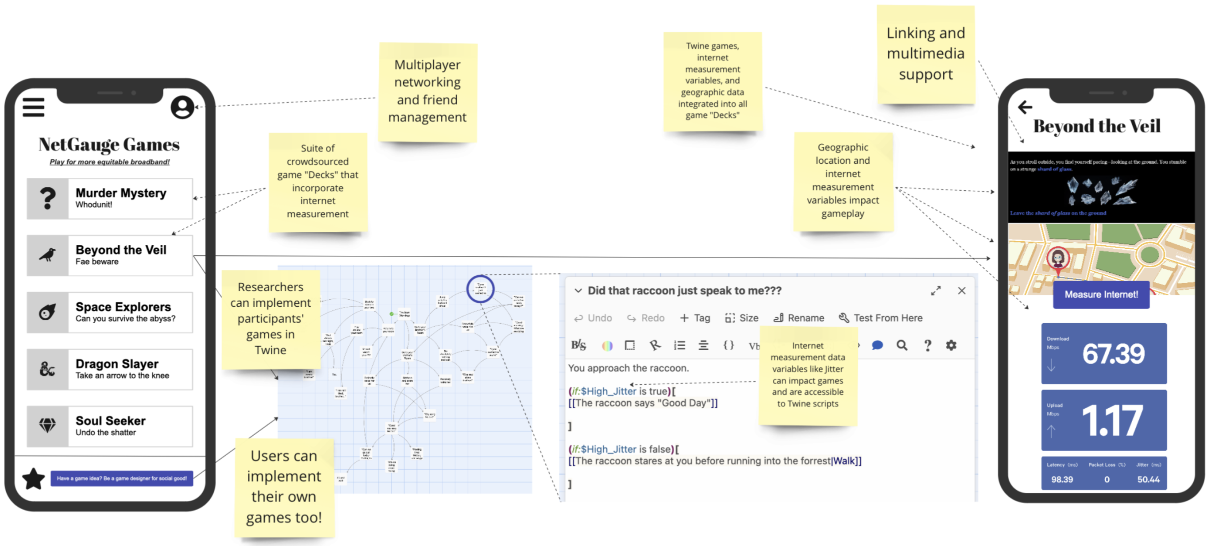


Figure 6: Speculative design of a broadband measurement mobile game that accommodates all of the concepts and mechanics of our participatory workshops.

only available when jitter is high) through a bespoke framework we will develop. The second mechanic involves geographic integration. This feature can be tailored to be either visible for players to locate specific waypoints or hidden to encourage exploration-based games where players seek out points of interest. The settings for these geopoints will be dynamic, influenced by the needs of the crowdsourced broadband coverage map and player preferences, including considerations for accessibility.

Overall, our participatory workshops have led to the identification of three key functional requirements that have shaped the speculative design detailed in Figure 6. The first is the "Decks" concept, realized through Twine, accommodating all game themes, player-driven mechanics, and interactive features. The second is a broadband measurement tool integrated with a custom framework that contributes data to the FCC and influences the "Decks" based on various network performance metrics, such as throughput speeds and jitter. The final requirement is a geographic feature for physical space exploration. Our future endeavors will focus on implementing and evaluating this speculative design. To arrive at this speculative design, we employed the emerging model from previous work [31] to organize each of the game concepts to a level of abstraction that allowed us to create a generalizable speculative design that supports all of the games, which is described further in Section 7.

7 DISCUSSION & FUTURE DIRECTIONS

7.1 Implications for Mobile Broadband Measurement (*RQ1*)

The serious purpose of the games we created during our design sessions was to encourage mobile broadband measurement by getting players to move around space and collect network performance data. As demonstrated in Section 5.3, games integrated the act of measurement in a few different ways. Some games, such as *Dragon Slayer* and *Zombie Apocalypse*, used measurement as a mechanism to reduce game friction, while others used measurement as a victory condition. While only five of the games were actually played as part of the warm-up activity, we note that games that tended to use measurement predominantly as a modifier seemed to result in more collections measured. Future work should explore how incorporating measurement through different types of mechanics might impact the number and the spatial distribution of measurements.

We also note that how participants conceptualized the task of geospatial measurement impacted their concepts of how the games operated over space. The games that scaled more directly to the design sites conceptualized geospatial crowdsourced measurement as a very decentralized and iterative effort that might engage multiple players independently playing in parallel through iterative levels in a game. Conversely, it seemed that the games that scaled much larger seemed to think of the measurement task as something that one individual had to engage in across the entire space of interest.

7.2 Insights for Serious Games (*RQ2*)

This work builds on and contributes to an emerging design model for characterizing serious games [31]. In previous work, the model was employed in the serious games for health domain [31], and in this work, it was used for community health through crowdsourcing internet measurements towards a future with more equitable Internet infrastructure investment. To adapt the model for this work, we changed the first spectrum from *Game First* and *Therapy First* to *Game First* and *Measurement First*. In general, we believe future work that employs this model can use *Game First* and any description that fits the serious utilitarian purpose of the game, so a more generalizable first spectrum could be labeled *Game First* and *Utility First*, but we also believe specificity is important, which is why we used *Measurement First* in this paper.

We found employing the model to categorize the diverse design concepts from our participants to be an integral step in our design process. The model was useful because it represents intermediate design knowledge in the form of a strong concept [61] that enables the research team to use a shared vocabulary to create a generalizable design artifact that encompasses all of the design concepts from our participatory sessions. This model is representative of a strong research through design approach [116] because, through the process of building our speculative design, we contribute new tacit knowledge to the serious games domain. In future work, as more serious games are plotted using the emerging model, generalizable insights may be developed for designers to make informed choices. For example, collaborative and competitive play are both motivating, but there may be situations where the model can provide insights on when to choose one over the other (or both simultaneously) based on the serious purpose of the game or the context of play. We found the emerging model integral to this work and believe it represents fertile ground for the domain of serious games.

7.2.1 Safety and Ethical Considerations. All of the games were designed in a "suspend your disbelief" techno-optimistic mindset [10]. As facilitators of design sessions, we did not remove any ideas based on whether or not they would be successful in practice. Leveraging a critical design lens [13], some games would likely need additional considerations to be safe if implemented. For instance, games like *Skinwalker Stories* and *Friend Finder* that involve location-based social matching between strangers can pose real risks. Aljasim and Zyko examine safety in the context of location-based mobile social matching apps [2], noting the body of evidence that these types of apps increase risks of sexual violence (against women in particular). Thus, it was unexpected that both of the games in our catalog that required location-based social matching elements were ideated by women participants. However, another potential rationale is while most male designers created experiences immersed in fantasy, the aforementioned games created by women are more rooted in reality, which may feel safer.

There are also important considerations around games that would require players to enter sovereign tribal lands and engage with cultural knowledge. While games like *Skinwalker Stories* reify an interest in culturally and geographically specific games, negotiation of the tensions of power embedded in the game space needs to be reconciled through a more critical design process. For instance, *Skinwalker Stories* was designed on the premise that Diné people living on Navajo Nation[4] would be willing to open their homes to predominantly non-Diné (and likely non-Native) players and share cultural stories about the shapeshifting skinwalker monster with them. However, the game as designed ignored realities that would need to be accounted for in an actual implementation. For instance, as noted by the participant who led the design of *Skinwalker Stories*, it is not always clear what knowledge and stories about skinwalkers are appropriate to share; indeed, it was not a game that we, the authors (who are not Diné), felt comfortable facilitating as a warm-up game in the subsequent sessions given our lack of ownership of the knowledge fundamentally embedded in the game. This sensitivity around cultural knowledge has been documented by other work in HCI and information science focused on designing systems to appropriately accommodate and represent Indigenous knowledge [1, 63]. *One takeaway for designing serious location-based games and play structures is the importance of self-authorship infrastructure that would allow cultural communities to easily create their own games and manage the rules surrounding who has access to play.*

Moreover, *Skinwalker Stories* also elicited a particular set of safety concerns. According to the US Department of Justice, 88% of Native American adults have experienced some form of violence in their lifetime. 94% of these victims of violence have experienced violence at the hands of a non-Native perpetrator. Unfortunately, due to gaps in the jurisdictional power of federally recognized sovereign tribes, many of these non-Native perpetrators are never criminally charged when these crimes are committed on tribal land [105]. Clearly, these realities mean that games like *Skinwalker Stories* might put already vulnerable populations at greater risk by facilitating physical and social contact in places where there are limited legal protections and longstanding patterns of violence. *Thus, an important implication for designing location-based games intended for play on tribal lands is that there should be close collaboration with tribal authorities. Moreover, co-design processes should foreground the safety of both players* and *the people who live and work in the spaces where the play takes place.*

7.3 Insights for Design Methods

Based on our experience using participatory design, bodystorming, and situated play design, we offer the following insights that might support future design efforts.

7.3.1 Props. While our design activities ultimately seek to inform the design of a mobile app that could be used alongside existing mobile broadband measurement tools, we wanted our participants to focus their ideas on moving around and interacting with space instead of focusing on what this might look like translated to a mobile phone. At first, this seemed to confuse participants, with several saying things like *"I mean I have an idea but it does not incorporate the internet speed thing at all"* (D3) as they worked through an idea with props. However, as design sessions progressed, participants began to lose their initial hesitation. The props were critical for helping participants reorient their attention to spatial engagement. Props were intentionally selected to take up space and encourage action in space or interaction with space. For instance, rubberband rockets and ping pong balls required participants to think about trajectory in space and try to match actions (throwing and launching) to that trajectory; yoyos and fidget spinners required participants to engage in manual manipulation; streamers and stakes marked particular spaces as significant. To encourage prop use, we communicated several times to participants that props were intended to be used creatively–and that we expected them to get broken in the process of design ideation. *Thus, it is important that props align with the intended focus of the design goal and that they feel safe and approachable for participants to interact with.*

7.3.2 Fostering Relationality. Most of the participants in a given session did not know each other prior to meeting at the session. However, because collaborative ideation through the game concepts

[4]Navajo Nation is sovereign tribal land in the region where we conducted our design sessions.*Diné* is the preferred term that members of Navajo Nation use to refer to themselves.

involved a certain vulnerability, it was important for participants to feel connected and comfortable with each other. It was also important to help the participants feel comfortable with the space they were in. Our warm-up activity (described in Section 3.6) helped support this in three ways, which is consonant with other design work [83]. First, the mirroring warm-up was a playful activity that gave participants permission to lead and participate in silly ideas, fostering group cohesion, warming up the body, and fostering a creative atmosphere [83]. Second, by having participants play a game that was ideated in a previous session, we demonstrated that the facilitators gave serious consideration to ideas generated by participants and that the concepts that emerged from sessions were meaningful beyond the context of the session in which they were generated, enabling iteration–an essential tenant of participatory design [33]. Finally, by actually playing through a game concept, participants were able to familiarize themselves with the design site and get a sense for the affordances of the space (e.g., trees to hide behind, pathways to follow), which is an integral consideration of seminaturalistic contexts for situated play design [6]. *Given these observations, we note that in situ participatory design activities taking place in collaborative groups would benefit from pre-design activities that help foster connections between people and place.*

7.3.3 Space. Given that different types of spaces tend to be more or less represented in crowdsourced data sets (e.g., rural places tend to be underrepresented while urban spaces are overrepresented), we believed it would be important to represent a variety of spaces across our design sites. As demonstrated in Figure 3 all three sites varied substantially. In spite of these differences, we did not observe that site type had a significant impact on game designs, particularly with respect to theme. Indeed, several game concepts matched each other rather closely, such as the *Dragon Slayer* and *Princess Saving Quest* games and the *Space Explorers* and *Planetary Packet Pilfer* games, even though they were ideated at different sites. We noted that some spaces required participants to be more aware of their surroundings than others. For instance, in the urban site, a group of unsheltered individuals were verbally belligerent towards the researchers and participants. While the researchers redirected the participants to move away from these individuals and made sure the participants still felt safe and comfortable enough to proceed, it made the participants in this session much more aware of how they were moving around space and how they might be perceived by a public audience. *Overall, these observations suggest that the affordances of the site itself may be incidental to the selection of game themes and that design facilitators might be able to leverage what is most available, accessible, and comfortable in order to ideate with participants.*

A related observation was the mismatch of spatial scope afforded by the sites and how space was conceptualized in some of the games. For *Space Explorers*, *Skinwalker Stories*, *City Scavenger Hunt*, and *Friend Finder*, the designers felt like they had a difficult time articulating their idea into space because they were conceptualizing mobility on a city scale or Indigenous nation scale. They expressed that it felt contrived to bodystorm their idea in a much more constrained spatial scope. *This mismatch points to different approaches participants might bring to thinking about geospatial games and how (depending on the design goal) it could be useful to consider in situ design across sites with different spatial scopes.*

7.4 Future Work

In the near future, the research team will implement a high-fidelity prototype of the "Deck" concept that we speculated on in Section 4 and conduct a usability study with participants who could use the games to collect mobile broadband data over a multi-week period. This type of study would examine how the games impact measures of user engagement with measurement in a near-term context, investigating how data collected via a designed prototype compared to data collected existing measurement tools with respect to the aggregate number of measurements collected, geographic diversity of measurements, and temporal patterns of engagement.

Future work would also look more broadly to how a playful infrastructure like the "Decks" concept proposed in Section 4 might facilitate longterm engagement with crowdsourced data collection efforts in general–not just broadband measurement. For instance, future investigations could integrate the "Decks" concept into existing community-based data collection efforts that use mobile devices to collect data. Research questions would answer: *How do games and play impact engagement with mobile crowdsourcing data collection over space and time? How does game design (with respect to the eight dimensions outlined in Section 5.2) impact temporal patterns of engagement?* Beyond initial "Decks" created by research teams and organizations that seek to support crowdsourcing, Section 4 also imagines a future world where anyone could create and upload their own game that could be used within a set of "Decks" supporting data collection. Thus, future work would investigate not only the creation of these game authorship tools, but also how users and organizations appropriate these tools to manage crowdsourced data collection.

7.5 Limitations

There were several limitations that may impact some of our conclusions. The first limitation was the representativeness of individuals who participated in the design process. While we sought to recruit students and staff from across the university by posting flyers broadly to email listservs of classes catering to all first-year students (regardless of major) and bulletin boards around campus, all of the participants were students in computing-related programs. While only one participant reported receiving formal training in game design, all of the participants reported having an interest in game design and development and playing games. This means that the majority of participants came to the design sessions with ideas about how games should look and operate. While this is not fundamentally problematic, it does mean that game concepts are likely to be influenced by mechanics and themes present in existing games. We also used a convenience approach for assigning participants to sessions across sites and this resulted in a relatively small number of participants in rural sessions before inclement weather made continued outdoor design activities infeasible. Notably, the rural co-design session was the chronological last and relied on games designed during urban sessions for warm-up, which could have influenced participants to engage with the space more similarly to those from urban sessions.

Another limitation is the relatively small number of participants. However, we do note that participants were ethnically and racially representative of the community for which the games were being conceptualized. The fact that themes and mechanics were repeated gives us confidence that the games that were conceptualized would be engaging to a range of individuals who might use geospatial gaming as a way to support crowdsourced data collection efforts.

8 CONCLUSION

Crowdsourced data sets are known to lack geographic representation, which can be problematic for geospatial crowdsourcing efforts such as mobile broadband data collection. Co-designing games and play represent fertile ground for motivating communities to measure their broadband. In order to ideate games that would promote better spatial representation in crowdsourced mobile broadband data sets, we engaged in a series of participatory design sessions with 11 participants in three geographically different sites across five sessions. The resulting game concepts revealed that while there was significant thematic variation, there were common mechanisms used across games to encourage measurement across space. This suggests that rather than creating a singular game to support mobile broadband measurement, it might make sense to create a single gaming framework that provides the common mechanics while allowing communities (or individuals) to easily create their own thematic overlay. In our discussion, we also highlighted important takeaways for serious gaming as well as for other researchers interested in engaging in participatory design efforts that critically engage with space.

ACKNOWLEDGMENTS

This work is funded by NSF CAREER Award #2145861. The work for this grant took place at Northern Arizona University and in Flagstaff, AZ. Northern Arizona University sits at the base of the San Francisco Peaks, on homelands sacred to Native Americans throughout the region. We honor their past, present, and future generations, who have lived here for millennia and will forever call this place home.

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