Game Changer: Accessible Audio and Tactile Guidance for Board and Card Games

ABSTRACT
Board games often rely on visual information such as the location of the game pieces and textual information on cards. Due to this reliance on visual feedback, blind players are at a disadvantage because they cannot read the cards or see the location of the game pieces and may be unable to play a game without sighted help. We present Game Changer, an augmented workspace that provides both audio descriptions and tactile additions to make the state of the board game accessible to blind and visually impaired players. In this paper, we describe the design of Game Changer and present findings from a user study in which 7 blind participants used Game Changer to play against a sighted partner. Most players stated the game was more accessible with the additions from Game Changer and felt that Game Changer could be used to augment other games.

Author Keywords
Accessibility; Blindness; Collaboration; Board Games; Visual Impairments; Audio Description.

CSS Concepts
• Human-centered computing–Accessibility technologies

INTRODUCTION
Board and card games have been a common form of collaborative play since the Ancient Egyptians invented Senet in 3000 B.C. [26]. In modern times, board games remain a popular pastime for friends and families, due in part to the added intimacy of playing a game face-to-face vs. looking at screens [8, 23]. Board and card games can serve many roles: as an exciting challenge for peers, as a collaborative social experience between friends, or as a way for family members to spend quality time together.

However, the design of many board games may unnecessarily exclude some players. Over 217 million people have moderate to severe vision impairments and 36 million are blind [35]. Like anyone else, blind and visually impaired (BVI) people enjoy playing games with friends, family, and even competitively [21].

However, the majority of board and card games are not accessible to BVI players as they often rely on printed text and visual distinctions such as colors, text, visual textures, and symbols. While it is sometimes possible to buy accessible versions of games (e.g., [17]), or to modify your own games to be accessible at home (e.g. [30]), the vast majority of commercial board and card games are inaccessible by default, and players may lack the skills, knowledge, or time to make their own games accessible.

Our work here is motivated by the goal of enabling players to easily adapt their existing games to be more accessible. For BVI players, this may involve adding audio or tactile information to a game [3]. Here we explore the use of tangible computing to enhance existing games by adding sounds and textures.

In addition to enabling BVI players to play more games, we must also consider how modifications to a game may affect the social and competitive aspects of gameplay. While in some cases a BVI player may want to ask another player for help, the situation may be further complicated if they are competing with that other player. Thus, building a platform for accessible games involves both designing an accessible interface to the game as well as ensuring that the accessible interface is fun and fair.

To explore the challenges and opportunities of making board games accessible through tangible computing, we introduce...
Game Changer, a prototype system that adds accessibility features to existing board games through a combination of audio descriptions and tactile overlays. We have iteratively built and tested this system on an existing board game, Hasbro’s SORRY!. We tested the augmented SORRY! game in a series of test games between BVI and sighted players. We found that BVI players felt the game was more accessible with the additions from Game Changer and felt that they could use Game Changer to augment other games.

The contributions of this paper are:
1) Guidelines for the design of accessible board games;
2) Game Changer, a system for extending board games with accessible audio and tactile feedback;
3) Feedback from a user study in which 7 BVI people tested Game Changer in a game against a sighted opponent.

RELATED WORK

Accessible Games
Currently, most research focuses on making computer and video games accessible [1, 2, 3, 7, 15, 25]. However, board games are largely still inaccessible to BVI players.

Accessible Board Games
There have been few research efforts in making board games accessible straight out of the box.

There are online stores [17, 24] that offer accessible versions of Monopoly and Scrabble. These versions augment text with Braille. Limiting people to these selections severely restricts the scope of participation in board gaming culture for those with impairments [20].

Sites like Thingiverse, a thriving design community for discovering, making, and sharing 3D printable things [30] can be utilized to acquire accessible versions of things, like an accessible Monopoly board [31]. Many of the designs either mimic or replace devices that are already available on the commercial market but at a lower cost [6, 12].

Gutschmidt et al. implemented Sudoku on a haptic display with sound to replace the computer interface for BVI people. Using gestures, a player is able to take notes, enter numbers, and undo their move on the display, all necessary to complete a game of Sudoku [18].

Filho et al. developed adaptation guidelines for board games to include BVI players and create a balanced experience for all players, where each player had complete autonomy. These guidelines are tested using low tech solutions, such as different textures and shapes [14].

With our prototype system, BVI players would be able to explore a wide range of other board games that they previously have been unable to play due to accessibility issues or lack of resources.

Accessible Collaboration
Research in accessible collaboration has focused on the relationship of blind and sighted people in the context of their home [10], shopping [34], workplace [11], computer programming [29], navigation [33], and online communities [12]. Studying the dynamics of these relationships gives us a better perspective of what challenges collaboration can conquer.

Collaborative accessibility helps accessibility. Inaccessibility results in sighted partners providing support and guidance to their BVI partner. Tasks can be completed independently if the partnership prepared [10]. This collaborative relationship could be utilized to modify a board game so BVI players can complete the game independently.

Even though the tools are provided to BVI people to perform their job, additional work is required to make things accessible [11]. While existing policies support reasonable accommodations for workers with disabilities, workers may hesitate to request accommodations [11]. This is a common theme regarding people with disabilities, because they do not wish to request too much help [4]. Our work aims to mitigate this theme by creating a system that they can interact with independently.

Social Play in Board Games
Social Play is described as active engagement with a game (through use of its controls or through observation and attention to ongoing game play) by more than one person [22].

When one feels controlled either in pursuing an activity or in how one accomplishes it, one’s sense of autonomy is diminished and subsequent motivation wanes [28]. The importance of autonomy in relation to motivation can be observed in our work. The user of the system is autonomous; they are in control of their actions and can make decisions keeping them engaged and motivated.

Xu et al. [32] observed the social play in board games and categorizes the five types of social communication that take place during gameplay.

1) Chores: interactions arising from activities needed to maintain or update game state
2) Reflection on gameplay: reacting to or reflecting on gameplay after a move
3) Strategies: discussion play before a move
4) Out-of-game: talking about topics outside of the game
5) Game itself: commenting on the game as an artifact

With our work, we focused on providing the information necessary for a player to engage and participate in all five types of social interaction.

Exploring the literature on accessible board games, accessible collaboration, and social play in board games, we
extracted important concepts across all domains that will inform the design of our system.

**BOARD GAME ACCESSIBILITY GOALS**

As mentioned above, designing accessible versions of games carries a unique set of challenges. In making a game accessible, it is important to not upset the balance of the game design, place players on equal footing, or reduce the entertainment value of the game.

**Design Goals**

Based on our review of accessible board games frameworks [14, 19, 20], and our iterations on our accessible board game prototype, we identified the following design goals for our work:

- **Equal.** Any information that is present in the visual parts of the game should be accessible in other media.
- **Fair.** The design of the accessibility features should not give any player who uses them an unfair advantage or disadvantage.
- **Fun.** The design of accessibility features should not fundamentally transform the gameplay or the ability to play the game as part of a social interaction.
- **Versatile.** The methods used to add accessibility features to the game should be applicable to other games as well.

In addition to these core goals, we identified some secondary goals that informed the design of our prototype:

- **Use available materials.** Whenever possible, any modifications to a game should use easily available materials, including the original board game and off-the-shelf technologies.
- **Reversible.** Any changes made to the game board itself should not impede play for any player. Ideally, any adaptations should be reversible.
- **Portable.** Players may wish to play their games in a variety of settings or may wish to bring their game elsewhere. The accessible version of a game should be as portable as the original game.
- **Tangible.** A part of the appeal of board games is their physicality [8], any accessible game should attempt to maintain the familiar tangible elements such as moving player tokens, drawing cards, and rolling dice.

Our design goals influenced our study design and interview questions.

**Core Gameplay Tasks**

There are many thousands of board games in existence. For example, the web site BoardGameGeek lists over 100,000 games. These games may differ widely in their physical form, use of visual media, and gameplay mechanics. As part of designing new games may involve creating new gameplay mechanics, it seems impossible to preemptively create accessibility solutions for every possible board game. At the same time, we were motivated to explore solutions that could be applied to many different games. Thus, we focused our work on the following core tasks that are common to many board and card games:

- **Recognizing cards and game pieces.** The system should be able to identify and read out any component of the game.
- **Describing the game state.** The system should be able to analyze the game board or play area and describe the current state of the game, including the location of any game pieces.
- **Describing changes.** The system should be able to identify and describe actions made by the player or by an opponent.
- **Directing movement.** The system should support the player in moving game pieces, drawing cards, or taking other actions within the game.

**GAME CHANGER**

We present Game Changer, a system that combines audio descriptions and tactile landmarks to enable BVI players to independently play board games.

**Proof-of-Concept Game**

Our initial prototype of Game Changer was designed to work with Hasbro’s SORRY! board game. The objective of SORRY! is to get all four of the player’s game pieces around the board and into your respective home zone before your opponents. Players draw cards to determine how far they can move and bump opponents back to their start if they land on the same space or draw a SORRY! card.

We chose SORRY! as our proof of concept for several reasons: because it is playable by younger and older players; because it has a relatively low learning curve; because it is a popular game; and because it contains many elements common to other board games, such as drawing and playing cards and moving game pieces on a board. Later in the paper, we discuss how this approach may be extended to support additional games.

**System Hardware and Game Modifications**

The Game Changer software runs on any laptop computer. The game is tracked by a Logitech C615 webcam, attached to a moveable arm. User input is provided via an attached USB 10-key keypad. Figure 2 shows the system hardware as used to augment the board game SORRY!.

In addition to the computer hardware, the game board itself is modified using low-tech tactile materials. We augmented the game board to identify the major regions of the board and to make it possible to find individual game spaces by touch. We used craft materials, specifically stick-on rhinestones and...
pipe cleaners, to annotate the board. Figure 3 provides an overview of the tactile annotations.

Figure 2. System setup that shows the laptop, webcam, numeric keypad, and game board.

The annotations are summarized as follows:

- Rhinestones were placed adjacent to each space on the board. Corner spaces were marked with two rhinestones.
- A large rhinestone was placed at the player’s starting position.
- The player’s “home base” was outlined with a pipe cleaner.
- The discard pile for game cards was outlined with a pipe cleaner.

Figure 3. Tactile modifications added to the game board to mark the regions of the board.

Finally, to increase the tactile differentiability of pieces, we fabricated a set of game tokens that were differentiable by touch (Figure 4). These pieces were laser cut from wood and painted, although they could be made using other means such as 3D printing or hand-cut cardboard.

This hardware setup was designed to be low-cost and easy for anyone to acquire. By replacing the laptop with a low-cost single board computer such as the Raspberry Pi, we estimate that the cost of the computer hardware would be less than $150 USD; the other material can be acquired for less than $20 USD.

Figure 4. Wooden game pieces that have been laser cut into the shape of circles, clovers, squares, and pentagons with ArUco markers on them.

System Software

The Game Changer prototype software is written in Python. The OpenCV library [9] is used to capture and process images of the game, and ArUco Markers [16, 27] placed on each game piece to recognize and track those pieces.

In general, Game Changer focuses on describing the state of the board and expects that players will know how to follow the game rules. We took this approach in order to minimize the amount of game-specific code that needed to be written, thereby making it easier to adapt Game Changer to support other games.

All data specific to a game (in this case, SORRY!) is stored in a comma-separated file. This file contains two pieces of information. First, each card and game piece is given an ArUco tag ID and a text description that will be read out when interacting with that card or game piece. SORRY! has eleven distinct cards, with each duplicate card receiving the same ArUco tag ID. For example, all cards with the number 7 were given the ArUco tag ID of 44 and the text description is the text verbatim from the card. There are three pieces for each player and each piece received a unique ArUco tag ID with the text description being the color and shape of the game with its current location. Second, each space on the board is marked with a space number and coordinates (relative to the game board). Because game locations in SORRY! are not numbered, we numbered the spaces based on the position of the BVI player, with their first space as 1, and increasing along the player’s path.

This game file was generated by hand. However, each game file should only need to be generated once, the process took about 45 minutes, and these files could eventually be shared online.

Tracking the Game State

The state of the game is tracked by the overhead camera and may be queried by the BVI player at any time. Currently, the camera is only activated when the user presses a key on the keypad; while Game Changer could track the game in real time, we found that doing so is challenging because players’
hands may occlude the board during gameplay, and real-time tracking was not necessary for our test game.

Game Changer currently tracks each player’s game pieces and the most recently drawn card. When the player requests information about the board state, Game Changer captures an image of the board, detects the edges of the board using Canny Edge Detection [13] and adjusts the image of the board using a perspective transform (Figure 5). The locations of the pieces in the perspective-corrected image are mapped back to the game file so that the space number for that piece can be determined.

Figure 5. Transformation of the real-world image to a perspective corrected image.

User Interaction
All audio feedback is initiated by the BVI player. Game Changer uses a numeric keypad as input and text-to-speech audio as output. Because system feedback could be used strategically against the player (e.g., requesting feedback about a certain aspect of the game could reveal the player’s strategy), both input and output modes are discreet: the BVI player can place the input keypad out of view and receives audio feedback via headphones.

For the Game Changer prototype, we developed a set of commands for querying the state of the board. While our initial prototype provides access to the SORRY! game board, we designed these commands to be generalizable across other board games. Table 1 shows example output for each of the commands.

In a typical turn, a player would draw their card and place it on the discard pile, press 4 to read the card, move their piece as instructed, and press 9 to determine whether any of their pieces had landed on a special space. During their turn, they might also press 1, 2, or 3 to learn the locations of their game pieces or their opponent’s, although they may already know this information from previous turns.

USER STUDY
To evaluate the effectiveness of Game Changer in supporting accessible board gaming, we conducted a user study in which BVI adults used Game Changer to play SORRY! against a sighted opponent.

Participants
We recruited 7 people with visual impairments (ages 29 to 49, 3 female) through mailing lists and local community organizations. All participants used a screen reader and read Braille at varying levels (Table 2).

<table>
<thead>
<tr>
<th>#</th>
<th>Action</th>
<th>Example Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Describes the BVI player’s pieces</td>
<td>“The yellow square is at space number 4.”</td>
</tr>
<tr>
<td>2</td>
<td>Describes the opponent’s pieces.</td>
<td>“The yellow square is at space number 4.”</td>
</tr>
<tr>
<td>3</td>
<td>Describes all pieces.</td>
<td>“The yellow square is at space number 4. The red circle is at space number 34.”</td>
</tr>
<tr>
<td>4</td>
<td>Reads the most recently drawn card.</td>
<td>“2. Move forward 2.”</td>
</tr>
<tr>
<td>5</td>
<td>Provides a summary of the available commands.</td>
<td>“Press 1 to hear the location of your game pieces. Press 2 to hear the location of your opponent’s pieces. Press 3 to hear the location of all game pieces. Press 4 to read the card. Press 5 for instructions.”</td>
</tr>
<tr>
<td>9</td>
<td>Checks to see if the player’s pieces are on any special spaces (such as a slide). If so, instructs the player on what to do.</td>
<td>SLIDE, move forward 3 more spaces</td>
</tr>
</tbody>
</table>

Table 1. Game Changer commands and example output.

All participants had previous experience playing board games. Three participants had previous experience playing SORRY!, the board game used in the study.

Procedure
Each session took approximately 75 minutes. After consenting to participate in the study, participants took part in a brief interview about their familiarity with technology and about their experience playing board games.

Next, the participant took part in two rounds of gameplay with a sighted opponent, who was also part of the research team. Because a game of SORRY! can be time-consuming, during each round the players only took a sequence of several turns.

Game One: Training Phase using Human Helper
During the first round, the participant played SORRY! on an original, unmarked board. During this activity, the participant was told to ask for help from a neutral human helper. This role was performed by another member of the research team. The human helper answered any questions the participant might have about the game and guided the participants when moving pieces and drawing cards.
The purpose of this round was not to support an A vs. B comparison with Game Changer, but instead to acclimate the player to the rules of the game and to capture any open-ended questions that a player might wish to know. As the goal of Game Changer is to support independent play, the fairest comparison would be to play SORRY! with no help or modifications. However, doing so would be difficult or impossible for most BVI players and so we did not include this condition in our study.

**Game Two: Play using Game Changer**

Participants played a second round of SORRY! with the Game Changer system. Prior to using the system, the participants completed an exploratory task that introduced the tactile features of the board and allowed them to get familiar with these features prior to using them during this round. The participant had no assistance except for the system and tactile features but was allowed to ask their opponent for information if the system could not provide it.

Following the two rounds of gameplay, participants took part in a brief interview about their experience playing the game.

**Data Collection**

Audio and video data were recorded by the research team. One member of the research team took observational notes. This member was seated next to the blind participant, while the first author sat next to the sighted participant and moderated the study.

**Data Analysis**

All data collected was analyzed for common themes with regards to each question asked during the pre and post interview. The common themes were discovered using affinity diagrams. The headings in the Findings section correspond to the themes discovered during affinity diagramming.

**FINDINGS**

**Current Gaming Activities**

In the initial interview, participants described their experiences playing board games. All participants had some experience playing games.

**Receiving Help when Playing**

Participants reported several strategies that they had used to make board or card games accessible.

First, several participants mentioned using a sighted person, whether it be a friend or significant other, to read cards for them and provide answers to questions similar to the first round of our study.

P5 explained how they used to "play Catan and Pandemic with my roommates, [who] would obviously help because it was too complicated to make accessible." P6 played a cricket game but "it was not in Braille so [they] had to have a sibling help [them] move the person."

Second, participants mentioned that they had purchased accessible games. P2 explained that, “I actually have the Braille Cards against Humanity, but it showed up after we had organized the game night for everyone to come and play Cards against Humanity.” Online stores exist that provide some accessible games but are not convenient. P1, P5, and P7 own a Braille version of Monopoly. P4 used 64oz. Games [17] to print Braille labels to stick on cards. P5 and P6 also have a Braille Apples to Apples and a Braille Scrabble.

Finally, several participants described how they had added Braille or tactile markers to a game board. This approach was often used to label items, such as the number printed on a card or the color of a space.

P1 noted that “for UNO and [others he put] Braille [on] the cards [himself],” he also recently acquired “Monopoly Deal and can’t wait to Braille that and start playing.” P7 explained how she tried to Braille the spots on Candyland, but the “pieces do not sit correctly on the board.”

**Accessibility Issues when Gaming**

Participants were asked to share their experiences with board games and what accessibility problems encountered when playing board games. With current off the shelf board games, many participants explained that they were not accessible because they do not know the location of the pieces or what the cards say.

P3 explained that, “I don’t know what’s there is the biggest one.” She was referring to the accessibility she encountered

<table>
<thead>
<tr>
<th>ID</th>
<th>AGE</th>
<th>GENDER</th>
<th>LEVEL OF VISION</th>
<th>DURATION</th>
<th>HAS PLAYED SORRY!?</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>30</td>
<td>Male</td>
<td>No vision</td>
<td>11 years</td>
<td>Yes</td>
</tr>
<tr>
<td>P2</td>
<td>32</td>
<td>Male</td>
<td>No vision</td>
<td>Since birth</td>
<td>No</td>
</tr>
<tr>
<td>P3</td>
<td>39</td>
<td>Female</td>
<td>No vision</td>
<td>5 years</td>
<td>Yes</td>
</tr>
<tr>
<td>P4</td>
<td>31</td>
<td>Male</td>
<td>Light perception</td>
<td>Since birth</td>
<td>No</td>
</tr>
<tr>
<td>P5</td>
<td>29</td>
<td>Female</td>
<td>Blind, but can see light and some shapes</td>
<td>Since birth</td>
<td>No</td>
</tr>
<tr>
<td>P6</td>
<td>34</td>
<td>Male</td>
<td>Light perception</td>
<td>Since birth</td>
<td>No</td>
</tr>
<tr>
<td>P7</td>
<td>49</td>
<td>Female</td>
<td>No vision</td>
<td>Since birth</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 2. Participants in the user study.
in playing games. “Like the Oregon Trail game parts of it I can know, even if they made the cards Braille, I still wouldn’t know the succession of pieces or what’s there.” She continued on, “Even SORRY, I can feel this piece, but I have no idea what is on the board.”

P1 explained that hidden information is the “biggest barrier for playing board games because pretty much anything else you can have people read. Sometimes games that have a high cognitive load or a very complicated board can be hard as well.”

The inaccessibility of board games prevented some participants from playing many games. P3 “currently [doesn’t] really play board games. [She] tried but couldn’t figure out how to make [them] accessible.” P4 explained that, “There are [games that I haven’t been able to play due to accessibility issues], the problem is I don’t know the names most of the games my friends play because it is not accessible I hear the name and was like oh I can’t play screw it.” P6 stated that, “Most of those board games that are not accessible I don’t even get them anymore. For the most part, I avoid board games other than the ones that I know that are available.”

P4 postulated the board games were often inaccessible because “creators are not thinking about blind people so therefore we have to think about different modifications to make the game accessible.” P4 went on to explain that “Even if the game can be made accessible then the resource to make it accessible is not readily available.”

**Game Play Activity**

*Game One: Play with Human Helper*

During the first round, participants were encouraged to ask the human helper any question about the game. Participants asked the helper a variety of questions such as the label of a card, the action taken most recently by the opponent, and the location of the game pieces.

Three participants relegated the task of moving their game pieces to the human helper, while other participants moved their own piece with assistance from the human helper.

*Game Two: Play with Game Changer*

All participants were able to use Game Changer to play the game. In most cases, participants made small talk with the opponent, supporting the idea that the system supported social play [32].

During this round, some participants struggled with placing their game piece on the correct space using the tactile features. However, participants were able to distinguish between their pieces and their opponents. In one case, P6 reached for a piece, recognized it was the wrong shape, and moved on to the correct piece.

**Game Changer Evaluation**

Following the second round, participants were asked to rate the accessibility of the unmodified game and the modified game. The ratings for these modes are shown in Figure 6.

![Figure 6. Subjective accessibility ratings of the two rounds.](image)

P2 explained that the unmodified game “wouldn’t be accessible because it was all visual.” P4 said that he would rate the unmodified game “zero out of ten in terms of accessibility. The first one had nothing in terms of accessibility.”

P2 explained that “[Game Changer] was a lot more accessible because I could do it on my own and count properly.”

**Accessibility of Rounds**

Participants were asked to state which of the two rounds, human helper or Game Changer, was more accessible. 6 participants stated that Round 2 was a lot more accessible. 1 participant stated the Round was a little bit more accessible.

P2 explained that “Round 2 was a lot more accessible because I could do it on my own and count properly.”

**Player Sense of Advantage or Disadvantage**

Participants were also asked whether they felt that using Game Changer gave them an advantage or disadvantage relative to their opponent. Responses to this question are shown in Figure 7.

P3 explained that during the unmodified game she was “at a big disadvantage. I felt like I didn’t know what was going on, I know I had a helper but that just makes it feel automatically not fun, so it’s just like a chore versus me actually playing a game. It is the basic thing that I had no idea what was on the board and no idea what the cards said unless I relied totally on someone else, just feels like a huge disadvantage.”

P4 explained that the unmodified game was “kind of a mystery because [I] didn’t know what was happening. I kept asking [the human helper] what card was he playing, what is happening, where things are, how far did he move. I was missing a lot of things, so I was at a disadvantage. Big disadvantage] because I didn’t have all the information and if [the human helper] wasn’t here, I would’ve said you know you play by yourself. I would have not played it you know I could’ve not done anything.”
Participants were asked if they would be able to play the board game with just the system and no other assistance. 4 participants answered yes with 2 participants being unsure (Figure 8).

P2 was not sure if he could use Game Changer independently “because I haven’t played it and I got a little confused with zones and things like that”. P3 said that she would be able to use the system but was not sure about how to set the camera up.

For the unmodified game, P7 felt “a disadvantage definitely. I couldn’t move my piece by itself. I had to continually ask where everyone was and what everyone was doing.”

For Game Changer, P3 stated they were not at a disadvantage “because I could know what was on my cards and what was on [their opponent’s] cards. I feel like if I didn’t know what was on her cards like she could do whatever she wanted, and I wouldn’t know and that would be a big disadvantage but the fact that at least I had the information to know I felt pretty similarly.”

P7 felt that Game Changer provided a “big advantage just because I could play it by myself. I felt we were equal; it was a lot better than the first [round]. I thought I was at the regular playing level, at the same level as my opponent.”

P6 explained that the first round provided a “big disadvantage, if you are playing with your friends and let’s say there are only two people playing and you have to rely on your opponent to tell you the cards, and they lose multiple games they could start telling you wrong information and you never know what is happening. You are totally reliant on someone else.”

P5 explained that the tactile features provided her with the information of “knew where the spaces were, knowing where my home was and where the beginning of my home layout of the board. P3 appreciated knowing everyone’s cards, “I like that I can know what both cards were. It felt a little more interactive doing that than just only knowing what I was doing.” P4 enjoyed “how [the system is] able to detect the cards and such.” P5 “really liked how it would read the cards.”

P1 recalled that “it was fun able to count my own squares.” P2 used the features because “it made things easier to count” and providing him with “some sort of frame of reference.”

P3 explained that she “[knew] where the spaces were so [she] could count them a lot better. I understand the start [area] a lot better with the tactile features and the whole safety zone, I didn’t even know that was there the first time that we played.”

P4 explained that the tactile features helped him “[understand] the orientation of where [he was], how things are traveling, and the distance between the squares. Also being able to know where to put the discard pile.”

P5 explained that the tactile features provided her with the information of “knowing where the spaces were, knowing where my home was and where the beginning of my home space and especially where you put the pawn after you move out of your beginning spot that was super helpful.”

Regarding the audio feedback, P3 appreciated knowing about her opponent’s cards, saying “I like that I can know what both cards were. It felt a little more interactive doing that than just only knowing what I was doing.” P4 enjoyed “how [the system is] able to detect the cards and such.” P5 “really liked how it would read the cards.”

Regarding the tactile features, P1 recalled that “it was fun able to count my own squares.” P2 used the features because “it made things easier to count” and providing him with “some sort of frame of reference.”

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I didn’t even know that was there the first time that we played.”

P4 explained that the tactile features helped him “[understand] the orientation of where [he was], how things are traveling, and the distance between the squares. Also being able to know where to put the discard pile.”

P5 explained that the tactile features provided her with the information of “knowing where the spaces were, knowing where my home was and where the beginning of my home space and especially where you put the pawn after you move out of your beginning spot that was super helpful.”

**How to Make SORRY! More Accessible**
Following the first round, participants were asked for their thoughts on how to make the game they just played accessible. Most of the suggestions involved adding further tactile support. Five participants requested raised borders around areas of the board, and all participants suggested Braille labels for the cards.

**Additional Games to Support**
Participants were asked to think about what other games they would like to use this system (Table 3).

<table>
<thead>
<tr>
<th>Game</th>
<th># who suggested it</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monopoly</td>
<td>4</td>
</tr>
<tr>
<td>Life5</td>
<td>3</td>
</tr>
<tr>
<td>Catan</td>
<td>2</td>
</tr>
<tr>
<td>Pandemic</td>
<td>2</td>
</tr>
<tr>
<td>Chutes and Ladders</td>
<td>2</td>
</tr>
<tr>
<td>Cards against Humanity</td>
<td>2</td>
</tr>
<tr>
<td>Trivial Pursuit</td>
<td>2</td>
</tr>
<tr>
<td>Clue</td>
<td>1</td>
</tr>
<tr>
<td>Cranium</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3. Suggested games that could be modified by Game Changer.

**DISCUSSION**
Our exploration of board game accessibility was successful in that all BVI participants were able to play independently using Game Changer. We found that participants were enthusiastic about the system and valued the ability to play independently.

**Effects of Experience**
Prior to the study, we were uncertain about how quickly participants would be able to learn to use Game Changer. Even for participants who were computer literate, we did not expect that any participants would have previously used an interactive tangible computing system.

Participants were able to quickly learn Game Changer but sometimes had some issues. P6 mentioned that he needed to practice the keypad commands before he was comfortable playing. Participants also sometimes forgot to use Game Changer’s audio input and reached for the board before remembering to use the system. This issue was particularly important at the end of the turn, as players sometimes forgot to Press 9 (which checked for the presence of any special, additional actions) before ending their turn. These usability issues will be addressed in future versions of Game Changer.

In addition to learning the system, participants also sometimes had difficulty learning or remembering the rules of SORRY! In general, we found that players who were already familiar with the game learned the system quickly, while those unfamiliar with the game seemed to take longer. These participants also sometimes forgot the rules of the game and needed to be reminded of them. This suggests that the system should provide better support for enforcing or reminding the rules of the game.

Another unexpected finding was that participants’ prior experience affected their desired feedback. This effect was especially noticeable with Participant 1, who had played SORRY! with his family while growing up. During his game, P1 often asked for more specific details about the board and the location of slides and other areas on the board. This suggests that knowing a player’s prior experience with a game might be useful in customizing audio feedback.

**Audio vs. Tactile Feedback**
We initially developed Game Changer with an emphasis on providing audio feedback, believing that this approach would be the most robust. We quickly discovered that many gameplay actions were assisted by the addition of tactile guidance. This is not surprising, as many existing accessible games involve adding tactile features and Braille to existing game components.

During the study, our participants shared positive feedback about both audio and tactile support, but frequently requested additional tactile feedback and Braille. Future versions of Game Changer will improve upon both audio and tactile feedback modes.

One major limitation of our current prototype is that, while we have developed a software workflow for adding audio feedback, adding tactile annotations is still a manual task. Future versions of Game Changer could partially automate...
this process by creating 3D-printable tactile annotations that could be attached to the game board.

Applying Game Changer to Other Games
We developed and tested Game Changer with a single game, Hasbro’s SORRY!. Testing Game Changer on multiple games at once was not a feasible option because developing this prototype involved many rounds of testing and development and getting the prototype to work with SORRY! provides many insights for future work.

However, despite implementing our system for a single game, we developed Game Changer with other games in mind, and we are confident that we can develop Game Changer into a generalizable approach.

For games similar to SORRY!, that have Roll/Spin and Move mechanisms, like Chutes and Ladders, The Game of Life, Parcheesi, Clue, or Ludo, we could simply create a new set of ArUco markers, attach them to the game pieces, and create a new metadata file that contains the game space coordinates and any special spaces if applicable. For games with additional components such as dice, these elements could also be tagged with ArUco markers (e.g., with a different ArUco tag on each face). In the future, game metadata files could be created by any member of the community and placed in a shared repository so that each game would only need to be annotated once, and future players could use that metadata file with their own game.

It is likely that some games contain features that would not be well supported by Game Changer’s current feature set. For example, Game Changer currently has no support for timed interactions. However, these gameplay limitations could be addressed in future work. Future versions of Game Changer could enable community members to upload their own modifications and rulesets, similar to Berserk Games’ Tabletop Simulator.[3]

LIMITATIONS OF THE STUDY
As mentioned previously, the current system is limited to a single board game. In the previous section, we have outlined how the system itself might be extended to support additional games. A further limitation is that, because we have only tested Game Changer with one game, we may be missing out on some undiscovered usability or accessibility challenges. We aim to better understand the limitations of this approach by incorporating support for more games.

An additional limitation is that the game sessions were relatively short. Additionally, participants played games against a member of the research team rather than a friend or family member. We invited participants to bring their friends or family along to the study session, but our participants did not find it practical to do so. In the future, we might consider deploying Game Changer into participants’ homes to capture more natural gameplay experiences.

FUTURE WORK
A major goal in extending the Game Changer prototype will be to support additional games and to enable users to add their own games. In the previous section, we have outlined the next steps for this work. We would like to extend the applicability of Game Changer by expanding its capabilities. Game Changer would be upgraded to include features that tracks opponent’s inventory for games like Monopoly and Catan, and tracks objects on the board in real time. We also intend to provide further customization options so that players can tailor audio feedback to their own preferences and experience levels.

In our current study, the Game Changer prototype was set up by a sighted researcher. Future versions of the system should provide guided instructions to enable BVI players to purchase a game, set it up, and play it, all without sighted assistance.

While our present work was motivated by the interpersonal and social benefits of playing games together, our evaluation did not provide much insight into the social dynamics of mixed-ability gaming. A future goal of this system is to support fully interdependent play [5], where each player can act independently as well as participate fully in collaborative work. We are curious about whether specific aspects of the game playing experience may influence players’ social perceptions; for example, is it more important to a BVI player that she is able to set up the game herself or that she can move her own game pieces? Can collaborative, mixed-ability gameplay help players to understand their partner’s experience? Now that we have developed a system to support accessible gameplay, we are both able and excited to explore how game designs and interactions may affect mixed-ability collaborative activities.

CONCLUSION
Many board games are not accessible to blind or visually impaired people because the majority of information is acquired visually. Few research efforts have been conducted in this area. To explore the opportunities and challenges of accessible board gaming, we created Game Changer, a system that provides tactile features and audio descriptions of the state of board games to blind or visually impaired people. Our findings show that the combination of audio and tactile feedback can be used to make existing games accessible and that participants valued the ability to play games independently.

REFERENCES


