Sound Woods: An Interactive Game-Based Learning Design for Inclusive Play Between Sighted and Visually Impaired Users

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Abstract: In traditional spatial learning for the visually impaired, preliminary understanding of spatial concepts is typically formed through oral descriptions by instructors prior to actual environmental engagement. However, this method is restrictive. This study encourages users to recreate and experience environmental spatial sounds within a realm by "Sound woods" using Orientation & Mobility Training. This enables users to engage in auditory training, focusing on "listening and positioning" to enhance environmental spatial cognition. For the visually impaired, who often have limited opportunities to interact with sighted individuals in their daily lives, video games offer potential avenue for social engagement. Traditional video games primarily rely on visual interaction through screens, posing challenges to visually impaired individuals owing to their limited eyesight. We designed a tangible video game that provides game-based learning, fostering communication between visually impaired and sighted individuals. Additionally, it provides sighted individuals the opportunity to experience space without sight, increasing empathy for the visually impaired, likely alleviating discrimination to some extent. This study underwent three rounds of testing, involving visually impaired individuals, individuals related to the visually impaired, and approximately 20 sighted participants in the workshop tests, incorporating their experiences and insights through interviews.

1 INTRODUCTION

The population of visually impaired individuals across countries and regions is significant. In Japan, approximately 1.64 million visually impaired people reported in 2007, a number expected to reach 2 million by 2030 (Yamada et al., 2010).Unfortunately, for these individuals, access to everyday life and leisure activities is often limited. For instance, children with visual impairments may interact with their environment less, which limits the educational benefits school activities accords to them (Freeman et al., 2017). Navigating the surroundings is a significant challenge for the visually impaired (Regal et al., 2018), necessitating consistent participation in spatial training and learning. Traditional methods of spatial training and learning often rely on oral descriptions provided by an instructor prior to actual engagement with the environment, but this approach has certain limitations.Therefore, this study proposes a shift toward entertainment-based and ubiquitous learning. It aims to engage users through the exploration of sound locations in a customized virtual world, utilizing gamified learning for Orientation & Mobility Training (O&M).

Studies exhibit that video games are an integral part of children and youth culture. Furthermore, these games are increasingly utilized by a growing segment of the population, particularly young adults (average age 25, with women accounting for 40%), and the proportion of players in other age groups is also rising (Archambault et al., 2007). However, current video games generally lack standardized methods for conveying on-screen information through non-visual means. Consequently, individuals who cannot utilize normal graphical interfaces, particularly those who are completely blind or have severe visual impairments (visual acuity less than 0.05), are restricted or entirely unable to access this significant aspect of youth culture (Buaud et al., 2002).

Game-based learning is defined as the use of games as learning environments where educational content is integrated into games, facilitating the learning process through engagement and interaction (Plass et al., 2015).In this study, combined with O&M Training,

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Figure 1: Sound Woods.

we developed a tangible video game "Sound Woods." The field of game design for the visually impaired has seen significant advancements in recent research. An exemplary design is the Binaural Navigation Game, a 3D audio game designed to enhance the abilities of both visually impaired and sighted players, focusing on training the visually impaired (Balan et al., 2015).Another example is "Em Busca do Santo Grau – Accessible Version," a 2D adventure game that is designed to be multidisciplinary and customizable for various educational levels (Neto et al., 2020). These instances demonstrate the potential of game-base learning design for the visually impaired.

Focusing on the design problems exhibited in Table 1 and considering the solutions provided, I concentrate on designing a game that is inherently enjoyable without the need for vision. Such games exist in many different forms, utilizing unique methods to engage players by incorporating other senses. For example, conversational games, tactile board games, and audio games, among others. This project ultimately adopts a tactile tabletop electronic game format, combined with audio feedback for design.

Before visually impaired individuals undergo real-world training for environmental spatial cognition, they often form preliminary impressions based on verbal descriptions from instructors. This traditional approach is somewhat limited. One of the major challenges faced by individuals with visual disabilities is being aware of what their current position is in different surroundings (Façanha et al., 2020). This game will recreate environmental spatial sounds in a virtual world, enabling players to train their auditory skills, particularly "sound localization," to learn about environmental spatial cognition. Humans can identify the direction and location of sounds utilizing differences in the timing and amplitude of sounds reaching their ears. By specifically, by discerning which ear the sound reaches first and the difference in sound intensity between the ears, the source can be perceived. This study utilizes stereophonic technology to implement 3D spatial environment sounds, as it can clearly convey the location of sounds. Incorporating this technology into the game is expected to support the training and improvement of players' sound localization abilities.

Table 1: Design problems and solutions.

Problem	Solution
For sighted individuals, playing games designed for the visually impaired may seem unnecessary in daily life, making it challenging to engage in these games intentionally. Additionally, there are concerns about fairness in these games, as differing visual abilities can make playing together potentially unfair for visually impaired participants.	It would be beneficial to reference games that can be enjoyed without visual elements. The design philosophy should shift, not forcing sighted individuals to experience an unseen environment, but rather transforming the absence of vision into an engaging challenge and point of interest in the game.
For visually impaired individuals, recognizing the position of characters or obstacles and determining if inputs are correct can be difficult.	Use various feedback that incorporates sound. Aim to provide a more accurate sense of distance and direction through headphones by stereophonizing the sounds within the relevant scene of the game.

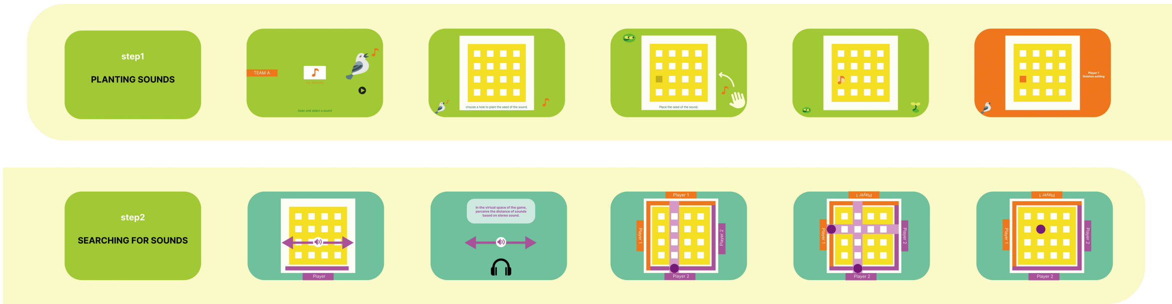

Figure 2: Game play.

2 IMPLEMENTATION OF THE GAME

2.1 Game Description

In this study, the developed “Sound Woods”(Figure 1) introduces an innovative interactive spacial learning experience, where both visually impaired and sighted individuals can participate together. The concept of the game revolves around “planting” sounds in a virtual space as seeds, where players are tasked with locating these “seeds of sound” through active listening.

In detail, at the beginning of the game, a player plants specific sounds into the virtual space. The opposing player, wearing headphones, distinguishes and searches for these sounds’ positions within the space utilizing stereo audio. Players then switch roles for the next round, and the player who identifies the sounds quicker wins.

By eliminating visual elements and focusing solely on auditory ones, the game’s design offers a fair and stimulating experience to both the visually impaired and sighted players. It aims to deepen the understanding and empathy for the world of those with visual impairments.

2.2 Game Play

The gameplay is divided into two main parts (Figure 2). The first part termed ”planting sounds,” involves Player 1 planting sound seeds in a physical box, aligning with specific locations in the virtual world. The second part, ”searching for sounds,” has Player 2, wearing headphones and utilizing the game’s 3D audio technology to perceive the distance and direction of the sound.The objective is for Player 2 to locate the sound seeds planted by Player 1 solely through auditory cues, eliminating the reliance on sight.

2.3 Game System

The ”Sound Woods” game system (Figure 3) utilizes the ESP32 to enable connection between interactive physical elements and the computer. The system employs magnetic sensors to receive information about where the sound seeds, crafted from clay and magnets, are placed. This enables players to participate directly in the game by physically planting seeds, with these actions reflected in the virtual world of the game.

- Structure of the Game System. The game system comprises two main components; the hardware interface and the software platform. The hardware interface utilizes the ESP32 and magnetic sensors to collect data on the placement of sound seeds and sends this information to the software platform. The software platform, powered by the Unity engine, reflects this data in the virtual world, arranging and playing back the relevant sounds accordingly.
- About ESP32. The ESP32 is a low-cost, low-power microcontroller chipset which is widely utilized in Internet of Things (IoT) projects and embedded system applications.
- Communication Principle between ESP32 or Arduino and Unity: The communication between ESP32 or Arduino and Unity utilizes serial communication protocols. This reliable method enables efficient data transmission between the hardware devices and computers.
- Data Transmission. When a player physically plants a sound seed, the magnetic sensor detects this action and sends the related data to the ESP32 or Arduino. Subsequently, the ESP32 or Arduino transmits this data to the computer through serial communication.
- Data Reception and Processing. The computer receives data through serial communication, and the Unity engine analyzes this data to perform the

Figure 3: Game system.

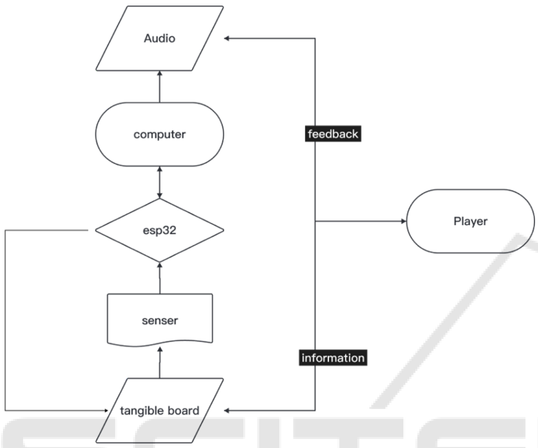

Figure 4: Communication process.

placement and playback of relevant sound seeds in the virtual world.

- Feedback Provision. The Unity engine provides visual and auditory feedback based on the placement and playback of sounds, assisting players to understand how their actions are reflected within the game.

2.4 Communication Process

The communication process (Figure 4) occurs in real-time, offering immediate feedback to the player, ultimately enhancing the gameplay experience. Additionally, this process improves the ability of visually impaired players to participate in the game through physical actions and interact with the virtual world through sound.

3 EXPERIMENT

This study collected a rich array of opinions through three rounds of testing, involving meetings with visually impaired related researchers and a workshop that involved 18 participants.

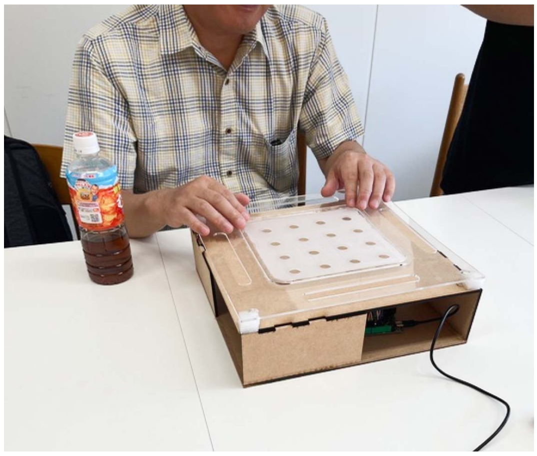

Figure 5: User test with Professor Hirose.

3.1 User Test with Professor Hirose

3.1.1 Method

Professor Hirose is a visually impaired cultural anthropologist who is a professor at the National Museum of Ethnology in Japan. He contributes to foundational research in anthropology. His research spans the history of religion in Japan, folklore, cultural theory of disability, and tactile culture. The user test for this study was conducted with Professor Hirose after an oral explanation of how the game is played, followed by capturing and analyzing his experience and opinions (Figure 5).

3.1.2 Result

With regards to the result and feedback, regarding the gameplay, Professor Hirose understood the rules clearly and completed a sequence of the game within one minute. He suggested that a clear indication is needed when a sound is found. Additionally, regarding the significance and application scenarios of the game, he reflected on his first experience at Hachioji Station, noting that starting from the exit and ascending the stairs, various sounds could be heard, and it was a good choice to calculate distances and scenarios by listening to these sounds. He pointed out that prior to actual activities, the game could provide training opportunities for visually impaired individuals.

3.2 Workshop at the National Museum of Ethnology

3.2.1 Method

In the workshop conducted at the National Museum of Ethnology in Osaka (Figure 6), approximately 20

Table 2: Overview of participants.

Number	Sex	Average Age
18	F(10) M(8)	39.5

Figure 6: Workshop at the National Museum of Ethnology.

sighted individuals participated, and 18 valid questionnaires were collected (Table 2). During the workshop, researchers explained the game's rules verbally with a demonstration that was carried out. participants were then paired up to take turns simulating visual impairment during the test.

3.2.2 Result

As for the results, the survey data (Tables 3, 4) indicates that the satisfaction with the game's feedback method was moderate, and the participants' understanding of the game rules was good. The evaluation of the sound design was also moderate, with suggestions made for the addition of everyday sounds like the crunch of potato chips, sneezing, animal calls, and musical instruments.

3.3 Meeting with Professor Kobayashi from Tsukuba University of Technology

3.3.1 Method

During the meeting with Professor Kobayashi from Tsukuba University of Technology, which caters to students with visual and hearing impairments, he shared numerous suggestions and related research insights. These contributions stemmed from his experience with "Sound Woods," involving the participation of a visually impaired student.

3.3.2 Result

Professor Kobayashi's feedback and advice included the following proposals:

- When utilizing only a keyboard, it's not possible to know the absolute position (which row and column). Utilzing a slider or other tangible objects could be a better solution. Alternatively, inform the player of their position during the response. Additionally, each cell could be changed into a physical button, with the player identifying the sound by pressing the button.
- Considering the integration the game with existing ones, Professor Kobayashi demonstrated a Go game designed specifically for the visually impaired. This demonstration exhibits a clever design for board games tailored for individuals with visual impairments.

4 CONCLUSIONS AND FUTURE WORK

This study describes the development of a tangible video game called the "Sound Woods," designed to bridge the experiential gap between visually impaired and sighted players. For visually impaired individuals, we developed a game that employs auditory learning through sound localization, which is crucial for environmental spatial cognition.

The effectiveness of the system was evaluated utilizing a questionnaire consisting of detailed queries on usability, learning outcomes, and social interaction. Positive responses indicated that the game succeeded in its educational intent, as participants demonstrated improved skills in auditory localization and enhanced environmental awareness.

The results of user tests revealed that the game has the potential to offer social, educational, and technical benefits. While still in its early prototype phase, the game aims to create an inclusive gaming environment for both visually impaired and sighted individuals, promoting equality and accessibility. It seeks to reduce discrimination and support auditory training. Additionally, it broadens the scope of game interactions and incorporates innovative gaming interfaces, thereby enriching the gaming experience.

Participants reported that the game was engaging and showed potential as a learning tool, highlighting its role in promoting unique social interactions. The game was effective in providing an inclusive experience, as sighted players also reported a deeper understanding and empathy for the visually impaired. The results of the questionnaire also suggest that there are many areas for improvement in the game, such as the need for better differentiation in game difficulty levels, and the introduction of a wider variety of sounds from

Table 3: Results of Questionnaire Part 1.

Question	1	2	3	4	5	Num	AVR.
Q1: Are you satisfied with the feedback and hints provided regarding sounds within the game?	0	6	5	3	4	18	3.28
Q2: Was the mechanism of planting sounds and using them for navigation within the game easy to understand?	0	1	5	6	6	18	3.94
Q3: After closing your eyes, did you feel the sound effects in the game sufficiently conveyed the environment and scenes?	0	3	10	2	3	18	3.28
Q4: Do you think the difficulty level in the game is appropriate?	0	5	3	6	4	18	3.50
Q5: Are you satisfied with the variety and timbre of sounds in the game?	0	0	4	8	6	18	4.11
Q6:Did you think "Sound Woods" would help to discover new methods of communication with visually impaired individuals?	0	3	8	5	2	18	3.33
Q7: This game is designed to be played without relying on sight, are you satisfied with your experience so far?	0	1	3	7	4	15	3.93

1-5: score. 1: Not at all, 2: Not much, 3: Neutral, 4: Somewhat, 5: Very

Table 4: Results of Questionnaire Part 2.

Q10:Do you see potential for this game in the fields of education, entertainment, or social interaction? Please share any other comments, ideas, or suggestions you might have.

User	Answer
USER1	I like the idea of planting sounds. Looking forward to improvements on explaining the rules better.
USER2	The idea of planting sounds was innovative, like sounds of eating chips or musical instruments. Making magnets in the shape of sprouts seems fun.
USER3	It was challenging to differentiate among the three types of sounds. Completely different sounds would be easier to distinguish.
USER4	There is potential for application.
USER5	Moving randomly seemed to end the game; more digital movement could make the game more engaging.
USER6	The search for sound sources reminded me of TREASURE IN DARK at Teikyo University.
USER7	-
USER8	Enjoying the game together was fun, and the controls were user-friendly.
USER9	High difficulty for sighted people was interesting; adding animal sounds might be good.
USER10	-
USER11	-
USER12	Adjusting the game level by choosing the sound volume with more or fewer seeds could be interesting. Other sounds, like those in a station, could be engaging.
USER13	The game was enjoyable once the rules were clear.
USER14	-
USER15	-
USER16	-
USER17	Increasing the variety of sounds would be better.
USER18	-

-: no answer.

everyday life in the virtual game world to enhance playability.

Professor Hirose, participating as a visually impaired individual, affirmed the game's extensive applicability, particularly its utility in spatial training for the visually impaired. Prior to navigating unfamiliar environments, such as new train stations, users could leverage the game's simulation of spatial audio cues in a virtual setting for preparatory learning. This feature underscores the game's potential as a practical tool for real-world orientation and mobility training for visually impaired users, demonstrating the game's capacity to extend beyond entertainment and into practical application.

The results of this study also suggest that integrating the learning component into gaming can enhance the accessibility and educational value of games for the visually impaired. These findings establish the potential of tactile video games as a medium for inclusive education and entertainment.

The aim of this study is to develop accessible game-based learning experiences that serve as effective platforms while promoting social inclusion. By implementing such a system, we aspire to enhance the equity of the gaming landscape, providing opportunities for entertainment, education, and meaningful social interaction to both visually impaired and sighted individuals.

In future work, "Sound Woods" will focus on further expanding its capabilities as a game-based learning tool for spatial orientation and mobility training. Key developments will include:

- Enhanced Sound Design. To better replicate real environments and therefore improve spatial cognition learning, the game will offer a more extensive selection of sounds for players to place in the virtual space. This could involve providing a broader range of environmental sounds or increasing the size of the playable area by adding more sensors. Such enhancements will allow for a more realistic and immersive auditory experience, aiding in the development of spatial awareness and navigation skills.
- Advanced Tactile Interfaces. The integration of advanced tactile interfaces will aim to provide a more engaging and interactive experience. By implementing haptic feedback systems, players will be able to experience different textures and vibrations, which will enhance their understanding of the virtual environment and add a new dimension to the learning experience.
- Customizable Difficulty Levels. Recognizing the varied abilities and experiences of its players, "Sound Woods" will include customizable difficulty settings. This feature will ensure that the game remains appropriately challenging and educational for all players, adapting to their specific needs and skill levels.
- Educational Content Integration. The game will integrate real-world spatial environments that require navigational learning, or combine storytelling, such as recreating the space inside a castle from a movie. This approach will not only make the learning experience more engaging but also provide cultural and interesting context, making "Sound Woods" an innovative tool for spacial learning.

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