The Cane Game: An Educational Tool for Orientation and Mobility

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ABSTRACT

Proficiency in Orientation and Mobility (O&M) is vital for people who are blind or visually impaired (BVI) to access physical environments and economic opportunities. While much engineering effort has focused on using technology to augment the practice of using a mobility cane, there is comparatively little work on using technology in service of teaching the use of the cane itself. We report a case study of a multi-year collaboration between assistive technology researchers and a certified O&M instructor at Perkins School for the Blind to utilize technology to create O&M teaching tools that use the concept of gamification to make such training more fun and effective. In this collaboration we adopted an action research approach, and through the application of action research HCI methods created several prototype systems for teaching O&M skills. These prototypes were refined to create the Cane Game: a system for teaching students cane sweeping technique using interactive music and sound. The Cane Game system can be constructed for less than $100 and is capable of being distributed at large-scale. A qualitative study of Perkins School for the Blind students' O&M educational trajectories while using the system illuminates the conditions in which this tool is effective as a teaching aid.

CCS CONCEPTS

• **Human-centered computing → Accessibility systems and tools**.

KEYWORDS

Orientation and Mobility, Education, Augmented Reality, Gamification

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1 INTRODUCTION

For people who are blind, improvements in orientation and mobility (O&M) skills lead to increased economic opportunity as well as psychological well-being. For example, while only 31% of working-age Americans with a visual disability are employed (compared with 69% of the general population) [11], individuals with better O&M skills have higher rates of employment [8, 9, 18, 19]. Similarly, while the link between blindness and depression is well documented [7, 14, 15, 23, 24], studies suggest that it is disability rather than blindness itself that is at the root of this linkage [23, 28]. For example, it was found that the ability to perform activities of daily living was *more* predictive of overall life satisfaction than was degree of vision loss [28]. Due to its importance as a foundational life skill, it is important that children who are blind or visually impaired (BVI) master O&M skills as early as possible.

People who are blind have been using canes as mobility tools for centuries [17], however, the field of O&M as an instructional discipline with its accompanying formalized curriculum (e.g., sweeping a mobility cane in a prescribed pattern to detect obstacles) began to form in the aftermath of WWII. Specifically, the U.S. military made an effort create a standard approach to help veterans who had been blinded in battle to acquire the skills necessary for safe, effective, and independent travel [27]. In the following decades, researchers have attempted to use technology to improve upon the design of the cane to enhance the mobility of folks who are BVI. For instance, researchers have added obstacle-detecting sensors such as lasers [5] and sonar [4, 6, 12, 22] to the mobility cane in an effort to increase the range at which obstacles can be detected. Others have utilized smartphone technologies such as GPS [1] and augmented reality [29] to provide automated navigation in unfamiliar environments (a capability not provided by the mobility cane). While there is little doubt that technology has potential to augment traditional O&M practice, in this work we explore the significant potential to use technology *in service of O&M education itself.*

Perkins School for the Blind provides educational services to both children and adults with blindness. While all students at Perkins School for the Blind have a visual impairment of some sort, many students have multiple disabilities (e.g., deafness, cognitive delay). In order to make instruction more effective and motivating, Perkins instructors have long made use of technology in areas such as music therapy and reading [3]. While all students receive instruction in O&M from a COMS (Certified O&M Specialist), there are fewer technologies for teaching O&M in a way that keeps students motivated to continue to learn new skills and practice skills until they achieve mastery. Additionally, for some people, using a mobility cane comes with a stigma [16]. For example, some kids and young adults wish to avoid being marked as different from their sighted peers and thus avoid using their cane. Others might be in denial about a progressive vision loss disorder, and not using the cane is a way to avoid admitting to themselves that they are going blind.

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Due to the dearth of research on tech-infused teaching technologies for O&M, the authors of this study initiated a multi-year collaboration to explore the idea of utilizing technology to make O&M education more motivating and effective through the introduction of game-like elements — a process known as gamification [25].

2 ORIENTATION AND MOBILITY TECHNIQUES

For non-visual travelers (folks who primarily, but perhaps not exclusively, travel using their non-visual senses), there are two primary O&M systems: the mobility cane and the guide dog [27]. While guide dogs confer many advantages in comparison to using a cane (e.g., being able to quickly move through physical environments), the high cost and effort in training and upkeep of guide dogs prevents many people from using them.

Beyond its role as a signal to others that the user is BVI, the mobility cane has many functions [10]. The cane acts as an anticipator for the path that lies just ahead of where the person using the cane is traveling. If the cane is wielded skillfully, it can detect obstacles, elevation changes (stairs, curbs, holes), people and other potential roadblocks for a traveler who is BVI. The cane should be utilized like an extension of the user's arm to "feel" the path forward. The ability to "feel" the path forward makes the cane the bedrock of safe travel. Second, the cane can be used to orient the user within their environment by detecting changes in surface texture (for instance if the user is going over a patch of grass or carpet) or detecting walls or landmarks that might provide information as to the user's position.

There are a number of techniques for using the mobility cane. The most basic technique is called *diagonal technique* in which the user holds the cane in one hand, positions that hand to one side of their body, and orients the cane such that it crosses over the body with the tip landing just outside of the shoulder on the opposite side [10]. With diagonal technique the user doesn't move the cane actively as they walk through the environment. While little action is required of the user, the technique provides less protection as the cane does not scan through as large of a volume as with other techniques (and hence would not find as many obstacles or hazards).

After learning diagonal technique, a student would typically learn to actively sweep their cane in order to detect obstacles as well as navigational landmarks. There are a number of techniques that folks utilize when actively scanning the environment with their cane (e.g., constant contact where the cane tip is always touching the floor or two-point touch where the cane is elevated above the ground during the middle of the arc), but these techniques all share the same basic attributes [10].

- The user should hold the cane in their hand with their hand located at the midline of their body, several inches in front of their belly button.
- The sweeping motion of the cane should come as much as possible from rotation about the wrist (rather than moving the hand laterally or rotating from the elbow or shoulder).
- The user should sweep out an arc that extends 5 centimeters on either side of their shoulders.
- The user should walk out-of-step with their cane sweeping motion such that their forward foot is on the opposite side of their body as the cane tip.

Another skill that non-visual travelers learn is how to walk down a hallway safely. For new students, they may use a technique called wall-trailing in which they place their hand that is not holding the cane in contact with the wall. Having a hand in contact ensures that the traveler will not veer into the center of the hallway, which can be a hazard.

3 DESIGN PROCESS AND PROTOTYPES

The collaboration described in this paper began with a meeting in late 2016 between Paul Ruvolo, an adaptive technology researcher, and Eric Jerman, an O&M instructor at Perkins School for the Blind. The motivation for the collaboration was to explore the use of cutting edge sensing technology to "gamify" the O&M skills that he was teaching to his students (e.g., how to sweep a cane with the appropriate range of motion or how to safely walk down a hallway). The focus of the work is on helping folks learn how to use the existing techniques more efficiently, rather than on replacing or augmenting existing techniques.

The structure of our collaboration closely follows the principles of action research in HCI [13]. Action research attempts to address the needs of society (particularly of marginalized groups) through joint collaboration between members of the public and researchers. Such collaborations necessitate deeply considering the ethical commitments and values of all participants and utilizing research approaches that honor these. In the context of our specific collaboration, it was important to understand Eric Jerman's ethical commitments to his students. Each of Eric Jerman's students had an Individualized Education Plan (IEP), which serves as a legal contract between the school, the sending school district and the parents governing goals to be worked toward over the course of the year. This ethical commitment had a number of implications for how we approached the research process. Most notably, rather than having all of his students test prototype educational technologies, Eric Jerman chose students to participate in the design process based on his assessment that the activities, as currently constructed, would be beneficial for his students' IEP goals.

3.1 Early-Stage Design Work

In the Summer of 2017, we visited Perkins School for the Blind to better understand the current curriculum and the educational technologies utilized therein. We immersed ourselves in literature on O&M techniques and watched case study videos on O&M teaching techniques to better understand the skills that we would seek to reinforce through our O&M educational games. Throughout this process, Eric Jerman served as an expert guide for the rest of the team. He emphasized the intersection of multiple disabilities and the O&M education process and how he tailored his approaches to individual students. We did several play tests with Eric Jerman where he showed us game-like strategies he used to motivate his students and improve their skills. These existing techniques provided inspiration and initial design directions for us to pursue in the development of prototypes.

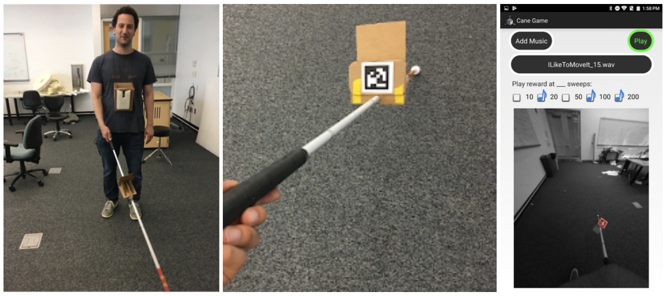

Figure 1: The prototyping environment we used to develop O&M educational games for students at Perkins School for the Blind. Left: the full system, including the harness to hold the phone and the tag to track the cane's motion. Middle: a close-up of the April Tag affixed to the cane. Right: a screenshot from one of our prototype games running directly on the Google Tango Smartphone.

Once the team had developed a basic understanding of O&M educational techniques for young children, Eric provided profiles for nine of his students (ages 8-10) who would try our initial prototypes. We used information about student interests (e.g., musical tastes or hobbies) to customize our prototypes (e.g., incorporating students' favorite songs) and to understand the relationship between student skills and student motivation. Particularly, we were interested in understanding Eric's opinion as to whether students were primarily motivated to practice a skill due to extrinsic factors (e.g., providing rewards) or intrinsic factors (e.g., due to their desire to improve or their curiosity to learn a skill). We created a two-by-two where we plotted each student on the axes of cane skills (beginning to intermediate) and motivational orientation (intrinsic to extrinsic). This visualization revealed a cluster of students who did not have well-developed cane skills and were also primarily extrinsically motivated. This tight cluster helped us understand some of the design opportunities for creating O&M educational activities (e.g., targeting the development of cane skills while using extrinsic reward systems to encourage practice).

3.2 Prototype Hardware Platform Details

We created a hardware platform for prototyping based on a Google Tango Phone (used for sensing) and a laptop (used for processing sensor data and implementing the mechanics of the O&M educational games).

3.2.1 Google Tango Phone. Google Tango is a now defunct experiment in mobile phone-based augmented reality. The device included the ability to accurately estimate its own 3D-motion (odometry), detect 3D-features of an environment using a depth-sensing structured light camera, and included a monochrome ultrawide-angle lens and a more conventional wide-angle RGB lens. In our prototyping system, the Google Tango phone was worn by the student using a shoulder / waist harness (see left panel in Figure 1). The position of the phone allowed us to develop O&M activities that were contingent upon the movement of the student and the location of 3D-features in the environment. We also attached an April Tag marker [20] to the cane to track its position using the ultrawide-angle camera (see middle and right panels of Figure 1). April Tags can be reliably identified in the camera feed and provide fairly accurate position tracking of the tag in relation to the camera (and consequently the cane in relation to the student's body).

3.2.2 Laptop for Data Processing. The data from the Tango was streamed wirelessly to a laptop running ROS (Robot Operating System) [21]. ROS allowed us to take advantage of many prebuilt packages for sensor data processing and enabled us to build our prototype games in the Python programming language. The laptop also allowed us to visualize the sensor and gameplay data, which was helpful for debugging. When we determined one of the game designs was refined and effective in Perkins' O&M curriculum, we ported the logic from the laptop to run directly on the Google Tango (see right panel of Figure 1).

3.3 Prototype Design and Reception

We developed four prototype games that we tested at Perkins School for the Blind. Each game involved the student using the phone / cane setup shown in Figure 1 and connecting to the laptop, which was running one of the four games. While one research team member orchestrated the prototype, another would take notes on how the student was responding to the experience.

3.3.1 The Cane Game. The Cane Game played music when the student swept their cane through the appropriate arc width (i.e., extending 5 centimeters on either side of the shoulder). The game would count out each sweep and then play the designated song at particular sweep totals (e.g., the 25th sweep or the 50th sweep). The game was designed to reinforce the effective use of the cane to scan for obstacles and help maintain the student's safety. The design of this game is more fully described in the rest of the paper starting in Section 4.

3.3.2 Cardinal Directions. Cardinal Directions would prompt the student to move forward, back, left or right a certain number of feet. The game would also prompt them to turn (e.g., turn left / right). The game was meant to be played in a large open area such as a gym and had the goal of helping students to improve their sense of space and distances.

3.3.3 Navigation Game. We implemented a navigation game based on affixing an April Tag [20] to the wall and using it to define a local mapping coordinate system. Before the student arrived, we used the Tango to map out the relative position between various points of interest (e.g., the elevator, Eric's office) and the April Tag. When the student arrived, we scanned the tag before placing the phone in the harness. This allowed the phone to re-orient itself to the saved map of points of interest based on the detected location of the tag. When the student was within a certain radius of a point of interest, its name would be announced. The student could also record a voice note at the point of interest that would be read by a computerized voice when they played the game again.

3.3.4 Wall-Trailing Game. We implemented a game that would play music when the student was within a certain distance of a wall. This game was designed to encourage students to walk on the right side of a hallway, which is safer as it helps to avoid collisions with others in the environment. The distance from the student to the wall was determined by the 3D-sensing camera included with the Tango phone.

3.3.5 Reception to Prototypes and Key Takeaways. The research team tested the prototypes with several students. The students ranged from 8–10 years old. Many of the students reported that they were excited by the novelty of the interaction and the fact that they would be testing out a new technology.

Due to the duration of the O&M training sessions (approximately 30 minutes) we were able to test one or two activities with each student. As a result, no single student was able to give feedback on all four of the games. The Cardinal Direction game was confusing to the students that tried it (they weren't sure why they were being instructed to follow particular patterns of motion). The Navigation Game was exciting to students when it worked properly, but due to motion tracking errors of the device, the system was not very reliable. In particular, the feature where students could record a voice note that would then be replayed at a later time was very engaging for one participant. The Wall Trailing Game was well-received by students. When students were close to the wall they were able to understand the contingency between their distance to the wall and the sounds the game was playing. When the students moved too far from the wall, they had difficulty understanding how to get the sounds to start again. The Cane Game was the most successful of the four prototypes in that students loved being able to listen to their favorite music or sound effects when they swept their canes. On the negative side, the detection of the cane's position was unreliable due to the camera failing to detect the April Tag. In particular, if the harness was out of adjustment or if the student rotated their cane such that the tag was on the bottom, the tag would not be detected. As a result, engagement with the activity was often disrupted by technical problems.

The process of having students put on the harness and attach the April Tag to their cane also proved to be quite cumbersome. For some students, the delay that this setup procedure caused exhausted their patience in testing the technology itself. Based on this experience, we decided to make the setup process for the system as quick and easy as possible. Of the four games, the Cane Game seemed to be the one with the most potential to be developed into a robust and engaging system for O&M education. As a result, we decided to carry the design of the Cane Game forward into subsequent years of our collaboration. To streamline the setup process and increase the robustness of the cane tracking component of the system, we decided to move from visual to inertial tracking.

4 CANE GAME SYSTEM ARCHITECTURE

The system is designed to be used by two people: the student and the O&M instructor. The instructor holds a smartphone (currently only iOS is supported), which connects through Bluetooth to two devices worn by the student. The first device is a speaker that is used to play audio from the Cane Game (e.g., playing music based on the student sweeping their cane with proper technique). At Perkins School for the Blind, students would either put the small portable Bluetooth speaker in their pocket or attach it to a belt loop using a carabiner. The second device worn by the student is a wireless, battery-powered inertial-measurement unit (IMU). In our tests we used Mbient Lab's MetaMotionR [2].

4.1 Wireless Inertial Measurement Unit and Cane Sweep Detection

In order to measure the sweeping motion of the cane, we employed a MetaMotionR IMU, which combines a 3-axis accelerometer (for measuring linear acceleration), a 3-axis gyroscope (for measuring angular velocities), and a 3-axis magnetometer (for measuring the magnetic fields, e.g., to get the direction of magnetic north). Crucially, the MetaMotionR and the coupling to the cane only weigh 14 grams in combination. Ideally we would like to be able to track the 3D-pose (position and orientation) of the IMU and since the IMU is affixed, rigidly to the cane, recover the 3D-pose of the cane itself. Since using inertial sensing to estimate linear motion (the position) of the IMU is considerably more difficult than estimating orientation [26], in our work we focus on estimating the orientation of the IMU and cane. A full discussion of our approach to sensing the motion of the cane is beyond the scope of this case study.

Our approach to cane sweep detection requires that the IMU is attached to the cane. In addition to needing to firmly attach the sensor, it is also desirable for the IMU to be able to attach quickly and easily to a wide variety of canes (with a variety of shaft diameters) as the Perkins School for the Blind students would grow impatient with long delays on starting their session. Finally, the attachment must be lightweight so as not to disrupt the normal use of the cane. Our final design of the attachment consisted of a customized, lightweight, 3D-printed part.

4.2 Evaluation of Cane Sensor Accuracy

We did an experiment to characterize the sensor's accuracy at detecting cane sweeps of a particular width. We measured 25 sweeps of the cane between two points with known displacement and found that the average error of the displacement as determined by the sensor and the actual distance was 1.0 centimeters. Eric deemed this accuracy sufficient for the purposes of providing feedback to Perkins School for the Blind students.

4.3 Smartphone App

The smartphone app both connects to the IMU and performs the calculations necessary to calculate sweep arc width and provides an interface for the instructor to setup the game and monitor the student's performance. The app also implements the gameplay by, for example, playing music or sound effects contingent upon cane sweeping.

4.3.1 User Profiles. In order to allow the Cane Game to be setup and customized quickly, we implemented a user profile feature. The user profile includes information such as the length of the student's cane (for calculating arc widths), the desired arc width of the sweep (based on a buffer of 5 centimeters on either side of the student's shoulders), a list of favorite songs (used in *music mode*), favorite sound effects (used in *sound / counting mode*), and difficulty level (used to set the tolerances on the sweep arc width that qualify the sweep as successful).

4.3.2 Music Mode.
In *music mode*, the app will play music from a playlist whenever the student sweeps the cane with an acceptable arc width. When a sweep is completed, the student's playlist will start. The music will stop when a sweep is recorded with an arc width outside of the desired range or if a certain, customizable amount of time has elapsed. The student can also stop the music at any time by putting the cane in shepherd's pose (this is when the cane is held such that it is parallel with the axis of gravity). In order to make music mode engaging for the students at Perkins School for the Blind, we found out ahead of time what their favorite songs were and used that to customize their playlist.

4.3.3 Sound Mode / Counting Mode.
In *sound / counting mode* successful sweeps either trigger a sound effect of the student's choosing or are marked by counting from a synthetic voice.

4.3.4 Sweep Triple Progress Bar.
The user interface for each mode shows a triple progress bar that allows the instructor to see, in real-time, whether the arc width of the student's sweep is "too narrow", "in range", or "too wide".

5 EVALUATION

To understand the experiences of students using the Cane Game, Eric utilized the game with a total of 28 of his students over a 4-year period. Consistent with our embrace of action research methods in HCI, Eric acted as both a designer (e.g., providing suggestions for game designs and feedback on particular systems) as well as a researcher who sought to understand the experiences of his students using the Cane Game. To describe our results, we chose an approach that focused on embracing the detail and messiness of the student experience by cataloging, in rich detail, the specific trajectories of particular students. As such, this study was not primarily concerned with the generalizability of the results, but rather on the dependability and confirmability of our data. This focus has led us to our current work of evaluating the transferability of the Cane Game to educational contexts outside of Perkins (see Section 7).

5.1 Hypotheses and Evaluation Process

Based on Eric's history working at Perkins School for the Blind along with our early stage design and prototyping work, we formulated four hypotheses regarding how students would experience the Cane Game.

(1) For students unmotivated to learn to use the cane, the Cane Game would increase motivation,
(2) For students with deficits in attention, the Cane Game would help students focus on cane training.
(3) For students lacking kinesthetic awareness, the Cane Game would help students develop awareness.
(4) For students new to using a cane but who were capable and eager to learn its mechanics, the Cane Game would help maintain their motivation for continued training.

In order to investigate these hypotheses, we adopted the following evaluation process rooted in Eric's ethical commitments to his students. Eric chose students to try the Cane Game who he felt were likely to have a good experience and avoided students who were known to be triggered by changes to their routine. Eric worked with students in the context of normal O&M lessons without any other members of the team present, Eric followed his normal documentation processes, but when using the Cane Game took notes as to whether the experiences of individual students either supported or refuted our key hypotheses. Eric's observations were provided to the rest of the team to design new features and refine the Cane Game.

Starting in the spring of 2018, a total of **28 students** have tested the Cane Game. In 2018, **13 students** tried the Cane Game for the first time. In 2019, **8 students** tried the Cane Game for the first time. In 2020 no students tried the Cane Game (due to the pandemic). In 2021, **7 students** tried the Cane Game for the first time. The average number of sessions each student used the Cane Game was 4.55 with a minimum of 1 and a maximum of 21.

6 RESULTS

Eric selected a set of case studies (i.e., individual student experiences) to enrich our understanding of our four basic hypotheses. In the interests of brevity we have provided one representative case study for each hypothesis.

6.1 H1: For students unmotivated to learn to use the cane, the Cane Game would increase motivation

Student Alpha had no light perception, had cognitive delays, and had little expressive language. He was intensely averse to physical cues and prompts–a light touch on his body or even on his cane could cause him to abruptly and aggressively slam his cane on the ground. When this happened, Student Alpha was usually so upset that the lesson was either paused or canceled altogether. When he first enrolled at our school, student Alpha did not sweep his cane for months, despite encouragement to do so. Student Alpha was happiest when left alone while he walked, even if that meant bumping into open doors and hallway corners, benches, etc. Often grim-faced during his lessons, orientation and mobility was not a preferred activity for him. During his lessons, he demonstrated a slow saunter and he walked for only short distances throughout the lesson. When Student Alpha used the Cane Game, he quickly discerned the causal connection between his cane movements and hearing his preferred music emanating from the speaker, and a huge smile broke out across his face. Student Alpha quickened his walking pace and he was soon covering lots of ground throughout the school's hallways. Student Alpha was eager to use the Cane Game and it clearly helped to improve his cane skills. The transformation in Student Alpha's skills and his demeanor were so sudden that staff members who witnessed him as he zipped down the hallways to the sounds of Harry Belafonte's "Jump In the Line" would often break out into congratulatory calls of encouragement and cheers.

6.2 H2: For students with deficits in attention, the game would help them focus on training

Student Delta was ambulatory, he was on the autism spectrum, he had cognitive deficits, fair expressive language skills and monocular vision (meaning he had no depth perception and was susceptible to tripping over changes in elevation and that he had trouble interpreting the distance of objects and people). Student Delta had over six years experience using a cane; however, in all those years, he had not developed the generalized skill of moving his cane back and forth in an effective arc width. Student Delta's attention wandered and tended to stray toward topics that he happened to be anxious about at any given time. Student Delta's cane skills were not of primary concern to him. Therefore, seconds after his instructor's verbal cues to sweep his cane, Student Delta tended to stop sweeping his cane. Student Delta was given the opportunity to use the Cane Game during multiple mobility lessons and he consistently chose the same song to play as his "reward" for sweeping his cane in an effective arc. Student Delta delighted in hearing his chosen song played and he grew frustrated when the song stopped. Student Delta learned that his own actions were in control of the music and that when he stopped sweeping his cane, the music would stop. The motivation to hear his favorite song was sufficient enough to help keep Student Delta's attention focused on sweeping the cane. Student Delta's cane skills improved while he used the Cane Game.

6.3 H3: For students lacking kinesthetic awareness, the Cane Game would help them develop awareness

Student Lambda was ambulatory, had low cognitive ability, walked with a slow, unsteady gait and had a tendency to teeter as if she was going to fall. Student Lambda had monocular vision which meant that she had difficulty knowing where her cane tip was at any given time. Student Lambda held her cane in a diagonal position and she did not move her cane more than a few inches side to side. Student Lambda had over six years walking with a cane yet she had not managed to consistently sweep her cane in an effective manner. When Student Lambda first used the Cane Game she was excited to listen to her favorite music with the app. However, the student's difficulty with motor coordination restricted her cane movements to halting sweep-stop movements, instead of consistent back and forth sweeping movements. This restricted movement meant that the Cane Game music did not play continually but was, instead, played in a start-stop manner. Student Lambda did not enjoy the experience of listening to her music in this way and she was unhappy with the experience of the Cane Game.

An adjustment was made to the Cane Game so that instead of listening to music as the cane moved back and forth Student Lambda could listen to a voice that counted starting at one and ascending with each successful cane sweep. Further adjustments were made on the Cane Game app to widen the "sweet spot" so that Student Lambda did not have to make an arc width to the same degree as a more advanced cane user. One sweep of the cane across midline and ending in an approximate arc meant that Student Lambda would hear a number counted out. Repeating the process back across midline in the opposite direction meant that she heard the following number counted out. The Cane Game was also adjusted to allow for funny sounds to be made with each cane sweep. Student Lambda enjoyed the counting and the funny sounds enough to keep sweeping her cane back and forth, thus making progress toward her goal of increasing the frequency and width of her cane sweeps.

6.4 H4: For students new to using a cane but who were capable and eager to learn its mechanics, the Cane Game would help maintain their motivation for continued training

Student Epsilon was a five year old student who was legally blind. He had some usable travel vision, but his lower field of vision was poor. Student Epsilon had a history of falling in response to changes of elevation (such as curbs), bumping into walls, objects and other people in front of him. Student Epsilon was new to Perkins and he had limited experience with a cane. He needed to learn the basics of how to hold his cane and how to use the cane to anticipate people and objects. Not uncommon with young students with low vision, he believed that he could see as well as anyone else and that he didn't really need to use a cane. At first, Student Epsilon simply held the cane in a diagonal cane position while he walked quickly down the hallways (not moving his cane tip back and forth while he walked). Student Epsilon was given the opportunity to use the Cane Game. He chose which song to listen to, and when he realized that in order to hear the song all he had to do was to sweep his cane back and forth, he happily moved his cane back and forth while he walked. Student Epsilon frequently asked to use the Cane Game while he walked during his mobility lessons. Through this experience, Student Epsilon began to generalize the cane sweeping technique into his cane use outside of his mobility lessons.

6.5 Negative Results

Student Tau was five years old with total blindness (no light perception) and in his first two years at Perkins School for the Blind he had never been willing to hold a cane. Student Tau had a history of running quickly through the halls and smashing his body and even his head into walls and objects because he had no way of knowing where these objects were. Attempts were made to offer him a cane and a toy foam sword to see if he would hold onto one of these but the mere mention of the cane or a cane substitute was enough to send Student Tau into a rage where he wildly swung the objects at instructors and students alike. Student Tau loved to listen to music and at one point he was offered the chance to use the Cane Game in the hope that the promise of listening to his favorite music would entice him into holding onto a cane. Student Tau did not agree to hold the cane or a cane substitute, even when he knew he would get to hear his favorite music. It appeared, the Cane Game was not enough of a support to encourage good cane technique.

7 DISCUSSION AND FUTURE WORK

Our experiences creating the Cane Game point to some additional areas of opportunity and further research but also highlight some points of caution that should be considered in future designs.

7.1 Avoid Distracting Gameplay Mechanics

For some Perkins students, the sounds played by the Cane Game proved to be rewarding to the point of distraction. For instance, when used using the counting mode, a student might sweep the cane rapidly back and forth in an effort to get the synthesized voice to count as fast as possible. Sweeping the cane so rapidly is not part of normal O&M practice and thus it is not a positive attribute of the Cane Game that it would promote this behavior in some students. The music mode, which continues to play music regardless of the rate of sweeping is an example of an appropriate game structure for students that have this issue with over-stimulation.

7.2 Tracking Student Progress Longitudinally

Another direction for the Cane Game is to use it as a way to quantitatively track student progress over time. The system could keep track of how many sweeps within the correct range of motion the student made in a session and whether sweeps outside the range tended to be too wide or too narrow. While this data is only a small fraction of the data that an O&M instructor would be tracking, it could be used as a component of the periodic reports that instructors must generate as part of students' IEPs.

7.3 Evaluating the Cane Game in other Educational Settings

Perkins provided a unique environment for this participatory action research. One of our current directions is to take our the results presented in this paper and see how well the current Cane Game will transfer to other educational settings. We are working with a team of O&M instructors from all around the Untied States who will be using the Cane Game with their students.

7.4 The Cane Game as a Tool for in-Home Practice of O&M Skills

A more radical adaptation of the Cane Game would be to position it as an in-home tool for students to practice their cane sweeping skills. Eric has found that students do not often practice their cane sweeping skills at home since, for example, they have family around to help them with mobility. Students may enjoy practicing with the Cane Game at home since it makes using the cane fun. Further, it is possible that adults will enjoy the Cane Game as a relaxing way to hone their basic cane technique while listening to music.

8 CONCLUSION

Our case study resulted in the development of the Cane Game: a system for helping students practice cane sweeping technique using a gamified approach to learning. In this paper we have presented the design process by which we arrived at the final form of the game (along with other prototype O&M educational activities). Our results shows that the Cane Game is engaging for students and leads to increased ability to maintain a cane sweeping arc of appropriate width. In the future we hope to enable more folks to utilize the Cane Game both as an instructional aid and as an aid for self-practice.

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