SenseBox: A DIY Prototyping Platform to Create Audio Interfaces for Therapy

Foad Hamidi, Sanjay Kumar, Mikhail Dorfman, Fayokemi Ojo, Megha Kottapalli, Amy Hurst
University of Maryland, Baltimore County (UMBC)
Baltimore, MD, USA
{foadhamidi, skumar5, dorfman2, fkme, mkott2, amyhurst}@umbc.edu

ABSTRACT
Customizable systems that enable children and adults with disabilities control audio playback can be used to support music therapy and speech-language therapy. We present SenseBox, a low-cost, open-source, customizable hardware/software prototyping platform to turn everyday objects into audio triggers for people with disabilities. Users can add tags to physical objects that when in proximity to SenseBox trigger the playback of associated audio files. SenseBox is designed with input from three therapists and an assistive technology expert. We detail our human-centered design process that took place over 16 months and describe a detailed example use case where we used SenseBox to create a customized accessible music player for a child with cognitive disabilities. This project underlines the importance of creating physical computing prototyping platforms that users with non-technical backgrounds can utilize to create customized audio interfaces for people with disabilities.

Author Keywords
Accessibility; DIY Assistive Technology; Speech-Language Therapy; Music Therapy; Audio Interfaces

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

INTRODUCTION
The emergence of a variety of low-cost electronic and computational prototyping platforms, such as Arduino and Raspberry Pi and compatible sensors and actuators, has made it possible for more people with non-technical backgrounds to experiment with new ways of interacting with their physical environments [11, 32]. The relatively low technical barriers to using these devices, along with their affordability and customizability, are often cited as factors that make them accessible to a range of hobbyists, makers and amateur artists and designers with creative ideas but limited programming or digital prototyping experience [6, 38]. For people with varying abilities and their therapists, special education teachers, parents and caregivers, the possibility of utilizing these platforms to create Do-It-Yourself (DIY) customizable interactive artifacts that could be used for expressive, educational and/or therapeutic activities is enticing [15, 17]. However, despite current efforts to create more accessible tools and processes to support participation in the creation of DIY interactive objects for people with disabilities and those who work and care for them, important technical barriers to participation still exist.

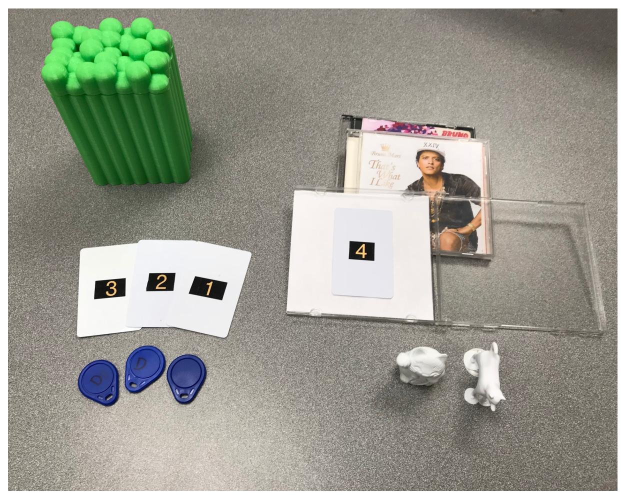

Figure 1. SenseBox consists of an audio playback module, housed in a 3D printed case (Left, top) and a series of RFID tags (Left, bottom) that can be embedded into physical objects (Right).

To better understand these barriers and to explore ways of overcoming them, we worked with two speech-language therapists, a music therapist and an assistive technology specialist in a series of 10 sessions over 16 months to design a prototyping platform for users with little or no prior programming or physical computing experience to create customizable audio interfaces using physical objects. *SenseBox* (Figure 1) is a Raspberry Pi-based prototyping platform that consists of an audio playback module and a set of Radio-Frequency Identification (RFID) tags that can be embedded into existing or fabricated (i.e., 3D printed, or laser cut) physical objects to turn them into accessible audio triggers for use in therapeutic settings. Each tag is associated with a user-specified audio file that is played back when an object embedded with it is in proximity of the playback module. Users can customize the system by (1) changing audio files, and (2) embedding tags in different objects. Neither of these mechanisms require any programming or electronics skills, making the system technically accessible to a wide group of users. We have incorporated these mechanisms to make it possible for SenseBox to be used to create audio interfaces that are adapted for each user, a quality described in previous research as important in creating accessible electronic interfaces for use in speech-language therapy [34], music therapy [25], and the "Holy Grail" of designing music and audio interfaces for people with disabilities [23].

The simple functionality of SenseBox, along with its flexibility make it useful for use in the context of speech-language therapy and music therapy, in which it is desirable for a client to exercise agency in generating alternative speech or audio sounds [9, 34, 41]. *Speech-Language Therapy* is a clinical practice used to support clients who experience difficulties in exercising communication skills [9]. Exercises used by speech-language therapists can support non-verbal clients or client with very limited speech to find alternative ways to express themselves and can include the use of Alternative Augmentative Communication (AAC) devices, such as communication boards [24, 34]. While a range of commercial AAC devices exist, they are often expensive, complex and their hardware is difficult to customize and adapt to specific users. *Music Therapy* is an established form of therapy in which music is used within a therapeutic relationship to address physical, emotional, cognitive, and social needs of individuals [9, 41]. After assessing the strengths and needs of each client, the qualified music therapist provides customized treatments which can include creating and/or listening to music. Music therapists use a variety of tools, including conventional musical instruments and digital music playback devices (i.e., iPods and CD players). The use of conventional devices can pose accessibility barriers to participation in music making for clients with motor or cognitive disabilities [33].

We next describe previous research in this area, followed by a description of SenseBox and the process that informed its design. We also describe a use scenario in which SenseBox was used to create an audio interface for a child on the Autism Disorder Spectrum (ASD). Finally, we identify a series of SenseBox's design features and limitations.

RELATED WORK

The TEI and HCI communities have long been interested in developing systems that use physical objects to trigger and manipulate audio in a range forms, including tabletop systems (e.g., [20, 39]), wearable instruments (e.g., [35, 40]) and game controllers (e.g., [22]), and augmented physical objects (e.g., [14, 18]). These projects are complemented by the development of several physical computing platforms, such as Bela [7] or Satellite CCRMA [12] that have been specifically designed for high-quality music synthesis and playback.

While many of these systems are designed for use by artists, designers or researchers, several Do-It-Yourself (DIY) platforms and kits are specifically designed for use by non-technical users (e.g., [14, 18, 28]). An example is Makey Makey, a popular DIY "invention kit" designed to let users connect conductive objects, such as conductive tape or pieces of fruit, to a computer to trigger specific mouse or keyboard button presses when the objects are touched [28]. Using this mechanism, users can interact with a variety of computer applications, including games and audio applications, using connected physical objects as input devices. While Makey Makey was designed for the general public, Rogers et al. used it as a mechanism to engage groups of older adults [32]. They found that their participants enjoyed using the kit for musical expression and came up with new application ideas. The researchers found it particularly important that the kit does not require programming skills to be used and presents a low barrier of entry for participants. Despite its strengths, some of Makey Makey's design features, including the need to connect objects to a separate computer using wires, and the need for users to hold a ground wire for the system to work, make it difficult to use with children with disabilities. SenseBox is inspired by Makey Makey and other similar designs, such as the Lilypad Arduino platform [11], that allow the incorporation of everyday objects in creating interactive interfaces. It aims to incorporate more features, such as wireless contact and avoiding the use of a separate computer, to make it easier to use to prototype accessible interfaces by therapists.

While some of the systems and platforms described above might have the potential to be used to develop accessible interfaces for people with disabilities, they are not specifically designed for them. Several other research projects have developed audio and musical interfaces specifically for people with disabilities, including people with visual impairments (e.g., [42]), people with motor disabilities (e.g., [5]), and people with cognitive disabilities such as Autism Disorder Spectrum (e.g., [31]) and dementia (e.g. [33]). Larsen et al. conducted a review of the current state of development in music-supported therapy, as well as recent trends in designing accessible musical interfaces for people with physical disabilities [23]. They identified the development of accessible musical interfaces that can be adapted for each user as the "Holy Grail" of designing in this space. SenseBox is designed with this goal in mind: it is built as a platform to make it possible for a wide range of audio interfaces, each adapted to the specific physical and cognitive needs of a user. Similarly, in a study of switches designed for children with limited mobility, Schaefer and Andzik stressed the importance of choosing devices that match a child's abilities and customizing activity outcomes to keep the child motivated to continue the effort required for sustained use [34].

Several projects have explored the possibility of using tangible and embedded physical interfaces to create accessible customized therapeutic devices for occupational therapy (e.g., [30]), music therapy (e.g., [21]), speech-language therapy (e.g., [13]), and educational systems for children with autism (e.g., [2]), as well as, deaf children (e.g., [16]). These devices are often designed in collaboration with therapists and offer a degree of customizability to let them adapt interfaces for their clients. Moraiti et al. presented a DIY-toolkit for occupational therapists and caregivers to create customized computer user interfaces for their clients out of soft objects [30]. The Skweezee system allowed therapists to embed electronics into existing or newly fabricated soft objects, such as pillows or matts, that could then be used to detect a range of tactile interactions, including squeezing, pushing, grasping and pinching. The interactions could be mapped to computer input actions, such as mouse clicks or keyboard input, which would then let the soft objects to be used as input devices to interact with a range of existing computer applications, including games. The system was evaluated with seven occupational therapists and one assistive technology expert who used it to create a range of potential solutions for clients. The therapists found the development of DIY platforms for the creation of diverse solutions valuable and emphasized the importance of developing platforms that do not require their users to have advanced programming or electronics prototyping experiences.

In a different study with three stroke patients, Kirk et al. found that using a digital drum set connected wirelessly to an iPad application to trigger percussion sounds in musical exercises led to significant levels of self-managements and an increase in functional measures [21]. The participants also reported high levels of motivation and enjoyment. The drums setup was fabricated in consultation with therapists who also helped choose a set of favorite songs to accompany for each of the participants. The researchers concluded that using digital musical instruments can offer health and therapeutic benefits to users and that it is important to have health professionals on board when deploying such systems to ensure their successful uptake.

Finally, several studies have explored design opportunities for new interactive interfaces in the context of speech-language therapy [13, 19]. In a study of five children with disabilities who use AACs in a special education school, Ibrahim et al. identified a series of design opportunities for future AAC solutions, including incorporating an embodied view of communication and designing to emphasize children's competence and agency [19]. The study found that the complexity of existing AACs creates a high-level entry requirement to their use for children. This often means the children have to undergo long trainings before being able to exercise agency in using them. The authors recommended the development of flexible communication technologies that place child users' agency in communication at the forefront of the interaction and develop and grow in complexity with their users.

In another study, Hamidi et al. presented TalkBox, a DIY low-cost open-source communication board for non-verbal users, that was designed as an affordable and customizable alternative to commercial AAC devices [13]. TalkBox was designed as a kit that could be assembled by therapists and adapted to meet the needs of each client. The researchers employed a participatory design process to develop the system in collaboration with special education teachers and therapists. While the physical form of the system could be adapted for each user, they still needed to touch a conductive part of the system in order to active the sounds. While we take a similar approach to DIY interface design, our aim is to develop a more flexible approach to allow a range of physical objects as wireless audio triggers during interaction.

In summary, previous research has shown that there are design opportunities for developing DIY prototyping platforms for therapists to create customized physical audio and music interfaces for their clients. Further, these interfaces should be designed so that non-technical users can utilize them to create therapeutic experiences for their clients that support client agency and self-expression. As we will describe in the next section, we have designed SenseBox with these goals in mind.

SENSEBOX: A PROTOTYPING PLATFORM FOR TURNING PHYSICAL OBJECTS INTO ACCESSIBLE AUDIO TRIGGERS

SenseBox (Figure 1) is a Do-It-Yourself (DIY) prototyping platform that allows users to create audio triggers out of existing or fabricated objects. It is primarily designed for use by therapists and special education teachers to create interactive audio experiences for children and adults with disabilities. In this section, we first describe SenseBox's design process which was informed by perspectives from its user community. This is followed by a description of SenseBox's design and functionality.

Design Process

SenseBox was designed using a human-centered design approach in which representative users were included in the iterative design process early on. Participants provided several rounds of feedback on design ideas to ensure that the system reflects their desires and needs [29].

Methods and Participants

SenseBox's design process took place over a period of 16 months where we worked closely with two speech-language pathologists (SLPs), a licensed music therapist, and an assistive technology expert. The SLPs and assistive technology expert work with children and youth with cognitive and motor disabilities and the music therapist works with both children and adults, including primarily older adults who experience cognitive disorders and difficulties due to aging. All of our participants are female and have worked in this field between 3-10 years.

In total, we conducted 10 interview sessions, each taking between 40 to 60 minutes, where we discussed different aspects of the system and how it could support therapy. Most of the sessions (7 out of 10) were conducted with two participants and the remainder with one participant. Employing an iterative design process, we fabricated and used a series of mockups and functional prototypes as objects for participants to reflect on and give us feedback about. These included a series of existing objects (e.g., empty CD cases) and newly fabricated ones (e.g., 3D printed rings and small animal shapes) to demonstrate the range of audio triggers that can be used with the system. Additionally, if they desired, participants could choose to keep the prototypes between meetings to think about them and provide us with their reflections afterwards. We incorporated participants' feedback into subsequent design iterations.

We encouraged the participants to ground their input on specific outcomes they desired in their practice and they often, anonymously, described how clients that they had worked with could benefit from aspects of the system. The design process described above resulted in a total of four working prototypes and six 3D printed mockups (Figure 2) and culminated in a functional prototype that we will describe in the next section.

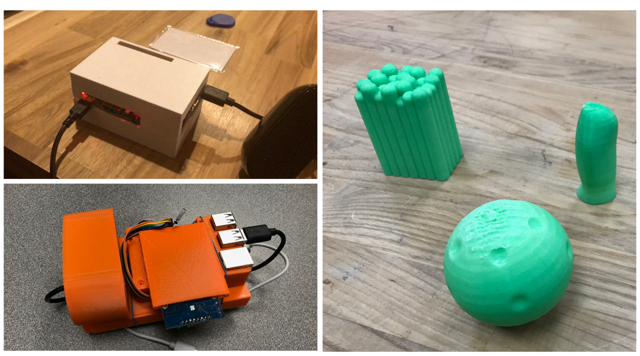

Figure 2. Two functional SenseBox prototypes (Left), and three 3D printed mockups (Right) used during the design process.

During the sessions, we took detailed notes that we annotated with our reflections after the meetings. We analyzed these notes using an inductive thematic analysis [9] where we coded the data and categorized them to identify emergent themes. The themes were then discussed with members of the research team and incorporated into the next design iteration of prototypes.

Design Considerations

We identified three themes in our participants' input that we will use to structure our design considerations below:

The Importance of Physical Objects in Therapy. Both the SLPs and the music therapist described how they use physical objects with some of their clients during therapy sessions. The SLPs described how working with abstract symbols, such as images or words, can be challenging for some of their clients. One of the SLPs described how some clients with cognitive disabilities had a hard time associating a 2D image (e.g., a picture of a ball) to a 3D object (e.g., a ball) or an activity (e.g., playing). For these clients, using physical objects, such as rubber balls, pieces of textile or wooden or plastic objects can be more effective. The SLPs described how using the objects is a stepping stone to learning more vocabularies and expanding the client's expressive abilities. One of the SLPs uses a set of everyday objects, including a fork, a hand mirror, a pen and a cup, among other objects (Figure 3) to introduce her clients to new vocabulary and ask them about their preferences. She described how for some clients, she uses physical objects to refer to activities. These can include a small rubber ball to signify going to the gym and a small baby shoe to indicate going for a walk. The SLPs described how these objects are often chosen to be appealing or meaningful to their clients. Additionally, the SLPs described how they use a range of objects with different textures and materials (e.g., metal, fabric, …) for some of their clients who have low vision.

Figure 3. A collection of physical objects used in Speech-Language Therapy to introduce clients to new vocabulary: During therapy the therapist would invite a client to touch and hold an object (e.g., a fork or hand-held mirror) and would repeat its name with the client.

The music therapist uses physical objects differently in her practice: She described how she often encourage her clients to use existing musical instruments (e.g., drums or shakers) to express themselves musically or participate in group music activities. She described these activities often involve her playing music on a piano or guitar with her clients listening, dancing, singing or playing along on an instrument with her. She stated that many of her clients find the use of existing instruments physically challenging and require guidance, practice and some level of customization of the instrument. For example, she described how one of her clients, a lady in her late 80's, enjoyed accompanying music by playing a small hand drum. However, her motor control and strength has been declining and she has difficulty making audible sounds by hitting the drum with her hands. To accommodate for these changes, the music therapist has been experimenting with drums that the client can play with her feet or with a mallet attached the sleeve of her shirt rather than one that she needs to grasp in her hands. The music therapist described how she is often looking for instruments, such as percussion instruments or portable musical keyboards that do not require a high level of skill or hand dexterity to play for her clients. Additionally, she mentioned that multisensory experiences are important and when choosing instruments or objects for her clients to interact with she tries to select a variety of textures (e.g., objects with fluffy or smooth surfaces and handles) when possible.

Supporting Client Agency and Self-Expression. The therapists described how it was important in their practice to support clients in exercising agency, in the sense of making decisions that somehow impact them [8]. For the SLPs, making choices and expressing them was an important goal of therapy that could lead to more independence and self-expression for their clients. The SLPs would deliberately choose words and phrases that were personally meaningful to their clients. They would then respond consistently when clients expressed these words and phrases. For example, one of the SLPs described how she was currently teaching her client to say “more” and “finished”. When the client expressed these phrases clearly, the SLP would respond to them by pausing current activities or giving them more of something that they desired (e.g., a food item). She described that once the client masters these phrases and the idea of them associating to consequences, she would move on to new ones. She described how the choices of words and phrases to practice also depends on a client’s background and culture. For example, she described how for one of her clients whose parents speak Spanish at home, she sometimes uses both English and Spanish phrases.

The music therapist described how supporting client self-expression and agency were important in her practice. She encouraged clients to express themselves musically and participate in group activities in order to find fulfilment and well-being. She described how two components were important to her clients expressing themselves successfully and exercising their sense of agency when doing so. The first component involved initiating and completing an action that has a desired outcome, for example hitting a drum with stick or pressing a button on an audio player. The second component involved perceiving that the completed action had a desired effect, for example by hearing the sound of a drum or music coming out of an audio player. She stated that this perception is important because otherwise clients might lose interest in the activity and become demotivated. She described how she considered both of these components when choosing which instruments or objects to use with her clients. For example, she described one of her clients who had limited strength in her hands and so she would choose a drum for her that could make a relatively loud sound when hit with a light stick. In this example, using the drum allows the client to easily initiate and complete the act of hitting the drum by raising a stick and hitting it against its face, and to perceive that this action had an outcome, by hearing the resulting sound of the drum. In contrast to the drum, using a violin with an untrained client would pose a barrier as making a pleasant musical sound on this argument requires a level of skill and hand dexterity.

The music therapist also described another aspect of client agency that was important in her practice: agency over one’s sound environment. She described how some of her clients are very sensitive to music that is nostalgic or holds strong emotional memories for them. Playing back such music without checking in with them can cause negative emotions in them, leading to sadness and hurt. She described how one of the hospitals she works at has guidelines on how staff should avoid playing music or tuning into radio stations without continuously checking in with clients. Further, the therapist stated that since emotions can shift over time and constant supervision is not possible in some cases, it is desirable to have accessible interfaces that older adults can use to stop or play music themselves.

Customizing Client Experiences. All of the participants underlined the importance of customizing therapy for each client based on their abilities, needs and interests. The SLPs described how they assessed a child’s communication and cognitive abilities in initial consultations and used this information and any information available from previous assessments to customize therapeutic activities accordingly. The assistive technology expert also described that part of the initial assessment, often conducted in collaboration with an SLP, would be a consideration of the types of assistive technologies that the client had successfully or unsuccessfully used before and deciding what existing solutions might be appropriate for them. She described a range of software and hardware solutions for speech-language therapy, including software apps, such as GoTalkNow [4], as well as, hardware solutions, such as Logan® ProxTalker® Modular [26].

For software systems, customization often took the form of changing parameters, such as the set of vocabulary or images used, for each client. A challenge for some clients was that using the visual interfaces of digital tablets, as well as, desktop and laptop computers, could be overwhelming or distracting. For these clients, the therapists opted for applications with simple interfaces with few onscreen elements. Other times, they would limit the use of digital systems altogether. For hardware systems, the form factor and physical features often needed to be customized and adapted for each client. One of the SLPs described how it is often difficult to change the physical form of existing commercial solutions beyond small changes since they are designed to be sturdy and not tampered with by users.

Additionally, they are often expensive, making it risky to void their warranty by tampering with their form. For example, she described that in addition to communication disorders, some clients have visual impairments which makes it desirable to change the color, size and even texture of buttons or other areas of devices for them. However, the therapists often had difficulty implementing these changes and settled on more minor change instead. Example modifications included adding a sturdy waterproof case to an iPad or adding a keyguard to a computer keyboard to make it easier to use by clients with limited motor abilities.

The music therapist also described how she customized musical activities based on specific clients' needs. Since she worked primarily with older adults her therapeutic goals were different from the ones described by the SLPs working with children and included motivating clients to make decisions, participate in group activities, exercise and make movements, and find ways to express themselves.

She identified how she often used her phone and speakers to identify music that her clients liked and reacted positively too. She stated that, "*YouTube is a music therapist's best friend*": explaining how such streaming platforms provide access to large samples of music to engage different clients. The music therapist also searched for ways to involve clients in music making or other participatory (e.g., dancing) activities. To this end, she looked for instruments that were easy to use for clients in individual or group sessions. As described previously, these instruments had to be chosen to be both easy to use and also make sounds that are perceptible by clients to keep them motivated. She asserted that for many aging clients it is difficult to use conventional instruments because of weakening motor abilities, especially in the hands. Also, for clients who experience dementia and other condition due to old age, it is often difficult to use digital interfaces. She stated that often "*one of the first things to lose is computer access*". Additionally, for many older clients who do not have experience using digital technology using newer systems (e.g., iPads) could be overwhelming. Thus, having a simple mechanism to activate sounds would support the inclusion of these clients in musical activities.

Summary. Based on our participants' input, a prototyping platform that would let therapists easily create customized audio experiences that enable clients with a range of cognitive and physical abilities to express themselves and exercise their sense of agency using augmented physical objects with different sizes, shapes and textures would be valuable in therapeutic contexts.

SenseBox System Description

SenseBox consists of an audio playback module and a series of Radio-Frequency Identification (RFID) tags that can be embedded in objects to turn them into audio triggers (Figure 1). A series of audio files each corresponding to a tag are stored on the module (and can be customized by users, as described below). Tags can be attached to existing or fabricated objects to turn them into audio triggers. When a tagged object is detected in close proximity of the audio playback module, the corresponding audio sound is played back.

Figure 4 shows a schematic of the SenseBox audio module that consists of a Raspberry Pi microcomputer connected to a RC522 RFID Reader, a battery and a USB speaker. The electronics are housed in a 3D printed enclosure (approximately 2.3" X 4.2" X 3").

The 3D printed enclosure is designed to incorporate participants' recommendations to make the system engaging and durable. By incorporating geometric patterns and a fastening mechanism, it provides an appealing appearance and protects the electronics from direct touch. We also intended it to be small enough for young users to carry. After experimenting with several forms (Figure 2), we decided on a rectangular shape with rounded edges and a top surface that consists of a series of randomly generated geometric cone shapes. The 3D model was designed using the Rhino 3D modeling software with the Grasshopper algorithmic modeling plug-in. We are currently developing a library of 3D models for a range of enclosures that can house the electronics and that users can choose from in the future depending on the needs and desires of themselves and their clients.

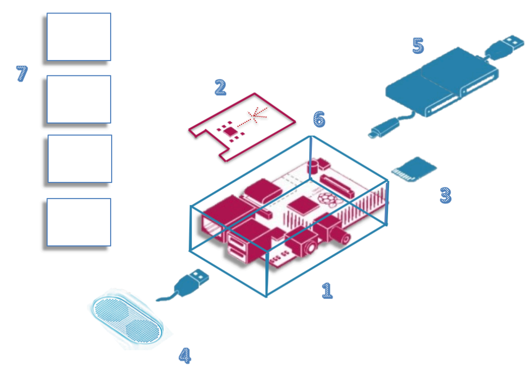

Figure 4. SenseBox Schematic: The electronic components of the audio playback module consist of a Raspberry Pi (1) connected to an RFID reader (2), with software on a SD card (3), and connected to a speaker (4) and a battery (5). All of these components are housed in a 3D printed enclosure (6) whose shape, color and texture can be customized depending on user needs and desires. The audio module plays back sounds when in proximity to RFID tags (7).

We have currently utilized three different sizes of RFID tags to embed in objects: credit card-sized tags (5" x 2.2"), keychain tags (1.1" X 0.8"), and small circular tags (0.8" X 0.8"). The RC522 RFID Reader operates at 13.56 MHz and can detect a range of commercially available tags. In our experience, the choice for which ones to use in an application depends on the size of the objects to be tagged: the smaller tags are more suitable for smaller objects because they will not add to their size. The system can work with a large number of tags.

The software running the system is based on the open-source Linux operating system and is written in Python as firmware for the device that loads automatically upon power up. By default, the system stores a set of RFID tag ID keys in its memory, each associated with an audio file also stored as part of the software, as a Waveform Audio File Format (WAV) files. For tags to be detected, their ID key needs to be registered in a database stored as part of SenseBox's software.

Non-technical users can utilize SenseBox as a DIY prototyping platform to create customized audio interfaces using two mechanisms: 1) loading their own audio files onto the audio playback module, and/or 2) adding tags to existing or fabricated objects. For mechanism 1, users can load their own customized audio files by formatting them as WAV files, naming the files to correspond to the RFID tag that should trigger it (e.g., naming an audio file that should be triggered by RFID tag 1 as S1.WAV) and copying the files onto a USB stick. Inserting the USB stick into any of the audio module's USB ports would then automatically copy the sounds onto the module. The new sounds would subsequently play back when corresponding RFID tags are in proximity to the sensor. This mechanism is implemented such that users can switch SenseBox vocabularies without having to interact with any code or display. Mechanism 2, adding tags to objects, can be accomplished using a variety of methods, including using glue or Velcro strips to attach tags to existing objects (e.g., a table or a plate), or newly fabricated objects (e.g., a 3D printed, or laser cut object).

SenseBox Usage Scenarios

SenseBox can be used in several ways. In one scenario, the audio playback module can be placed on a table or similar surface, for example a wheelchair tray. If more stability is needed, it can be fastened to the surface using Velcro or glue strips. When tagged objects are brought to the proximity of the sensor, a corresponding audio file is played back. Since in this scenario the audio playback module remains stationary and tagged objects are brought to its proximity, it is best suited to using small tagged objects and for users who would have difficulty with grasping and holding the audio module. The objects can then be used in speech language therapy exercises when therapists want to teach the name of objects to their clients or encourage them to communicate using objects (e.g., objects that symbolize activities or greetings). For music therapy exercises, musical sounds can be used that are activated when a client brings an object close to the module.

In a second usage scenario, tags can be attached to potentially larger objects (e.g., tables, chairs, …) and a user can hold the audio playback module with their hands and bring it close to the tagged objects to trigger the playback of corresponding audio sounds. An example of this usage in the context of therapy is when a client with visual impairments is encouraged to explore a space or environment and scan tags in a room using SenseBox. Needless to say, the two scenarios described above can be combined in a single therapy session and a therapist may choose to keep the module stationary only part of the time and for specific exercises.

The current design of the system also presents limitations where there is a practical limit on the number of objects that can be tagged and used for communication or musical participation activities. Additionally, the system is unsuitable for socially contextualized communication (e.g., in a classroom setting) due to the limited number of tagged objects that are practical to use by a single individual. However, previous research has recognized the importance of using accessible, yet simple, interfaces, such as SenseBox, as bridging devices to scaffold the learning experience needed to move on to using more sophisticated AAC systems [34].

Example Use Case

To illustrate how SenseBox can be used as a prototyping platform, we describe a real-world use case in which we used SenseBox to create a customized audio interface in the form of an accessible music player for a child who is receiving therapy from two of the SLPs who participated in the project.

The music player is designed for a 16-years-old boy who is on the Autism Spectrum Disorder (ASD). He is non-verbal and has low-vision. He uses corrective lenses, which he occasionally refuses to wear. He is generally more responsive to audio prompts than visual prompts. His SLPs have been using 3D objects, such as a rubber ball or a baby shoe to communicate activities, such as recreation or walking, on his schedule. He is interested in music and is especially fond of the popular artist Bruno Mars. Sometimes he finds Bruno Mars' YouTube videos on an iPad by looking for his pictures displayed as part of the website's interface. However, using YouTube poses difficulties because the many buttons and on-screen elements can be confusing and also navigating through the website can lead to undesired or inappropriate videos and needs to be done under adult supervision. The SLPs described that currently, one of their therapy goals for this individual is to teach him about cause and effect through the use of images and objects that correspond to specific outcomes and activities, a common activity in speech language therapy [34]. Acquiring these skills would improve his overall communication, leading to gains in independence and quality of life. To this end, the SLPs recommended using SenseBox to create a customized Bruno Mars music player for him that he could activate himself.

The customized music player was created by first identifying three Bruno Mars songs that the child likes and also finding images that correspond to them on YouTube (including album covers and pictures of the artist). The three songs were then copied to the SenseBox playback module using the process described above and each associated with an RFID tag. The RFID tag and images were each attached to one of three empty CD cases, that would serve as an audio trigger for the music player (Figure 1, Left). CD cases were chosen because they are large enough for the child to use and light enough for him to move close to the audio playback module to play a song.

SENSEBOX'S DESIGN FEATURES

SenseBox's design incorporates several important features based on our participants' input. These features confirm and build on previous recommendations for designing accessible physical interfaces for people with disabilities. We believe SenseBox's design illustrates how these features can be incorporated into the future design DIY prototyping platforms for therapists, special education teachers and others who work with people with disabilities.

Simplicity. SenseBox does not require the use of a visual interface and only relies on audio and physical interactions. This feature is based on the participants' input that described how visual interfaces can be distracting or complicated for many users with disabilities, an observation made by previous research on systems designed for children with disabilities [13, 19]. Additionally, we have intentionally kept the functionality of the audio playback system simple and currently limited to the playing back of audio files, rather than other functionalities such as looping, adding effects to or recording new audio files. While these functionalities could be added to the system if users want them, we have prioritized simplicity and avoided adding extra features to keep the interaction.

Customizability. The importance of customizability was underlined both by input from our participants and by previous research (e.g., [13, 19, 23, 25, 30]). As described before, we incorporated two mechanisms for non-technical users to customize SenseBox's hardware (i.e., physical audio triggers) and software (i.e., embedded sounds). RFID tags can be attached to objects of different sizes and textures and users can load musical sounds, speech samples, or relaxing sounds among others onto the audio playback module. This DIY approach allows therapists to change the system's physical form to meet the needs and desires of specific users as well as, their preferences as to the appearance and attractiveness of the physical device. These are key differences of this approach from existing switches and other alternative input devices that have fixed form factors [34].

Affordability. We chose to use open-source, affordable and widely available computational components (i.e., the Raspberry Pi and RC522 RFID Reader) to implement SenseBox, in order to make it easier for users to fabricate and modify it themselves in the future. Currently, the cost of building a SenseBox from scratch is under $120. While more sophisticated physical computing platforms, such as Bela [7] or Satellite CCRMA [12], that are designed for high-quality music playback could possibly provide a better audio performance than the current implementation, our choice of using more available materials that still satisfy the performance requirements of the system is in accord with ideas behind the DIY approach that prioritize platforms that can be assembled and fabricated by users themselves [15, 17]. In the future, we plan to make SenseBox's design, including the software, 3D models and instruction on how to assemble the system, available online to make it possible for users to assemble and fabricate variants of the system themselves.

Accessibility. The features described above all contribute to the overall accessibility of the system, in the sense of lowering barriers to access for its users. The simplicity and customizability of the system make it possible to use it to create audio interfaces that a wide range of adults and children with different motor and cognitive abilities can use. The non-technical mechanisms to customize it lower technical barriers to its use for therapists and other professionals who might not have programming or design experience. Finally, its affordability lowers financial barriers of access and makes it possible for users situated in a range of socio-economic settings to use it. In these ways, we hope that SenseBox exemplifies a new generation of DIY physical computing prototyping platforms that make physical computing suitable for a wide range of applications and accessible to new user populations, beyond professional technologists and designers.

LIMITATIONS AND FUTURE WORK

In this paper, we focused on the design process of SenseBox without a formal evaluation of the system. In the future, we plan to evaluate the system with representative users including therapists, special education teachers and children with disabilities. We also currently focused on therapists' perspectives. We recognize the importance of including input from participants with disabilities [37] which we are planning to do in the future. Additionally, we will refine SenseBox's design further using a participatory design approach in which we ask participants to identify new audio applications that we will then co-design with them. So far, we have focused on using a single audio playback module. We plan to explore implementing a network of multiple SenseBox units that can communicate and interact with each other using a Musical Instrument Digital Interface (MIDI) interface [27] or taking advantage of Raspberry Pi's Sonic Pi built-in open-source audio programming environment [36]. This approach might allow groups of users to interact with each other using a network of SenseBoxes.

CONCLUSION

DIY prototyping platforms can enable users to create customized audio interfaces in support of music and speech-language therapy. We presented SenseBox, a DIY prototyping platform to enable therapists to design audio interfaces that fit the needs and desires of their clients.

SenseBox is implemented using a Raspberry Pi computer and a series of sensors. This project demonstrates that open-source DIY components can be used by non-technical users to create accessible interfaces for use in therapeutic and relaxing contexts. We hope that SenseBox inspires future platforms that combine the computational power of low-cost embedded hardware with usability features that allow non-technical users to create their own therapeutic and expressive applications.

ACKNOWLEDGMENTS

We would like to thank our participants for their time and invaluable input. This research is supported by the National Science Foundation under Grant No. IIS-1451661. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

1. Ankur Agrawal, Glen J. Anderson, Meng Shi, and Rebecca Chierichetti. 2018. Tangible Play Surface Using Passive RFID Sensor Array. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* (CHI EA '18), Paper D101, 4 pages.
2. Andrea Alessandrini, Victor Loux, Gabriel Ferreira Serra, and Cormac Murray. 2016. Designing ReduCat: Audio-Augmented Paper Drawings Tangible Interface in Educational Intervention for High-Functioning Autistic Children. In *Proceedings of the 15th International Conference on Interaction Design and Children* (IDC '16), 463-472.
3. Jesse Allison and Timothy Place. 2003. SensorBox: practical audio interface for gestural performance. In *Proceedings of the 2003 Conference on New Interfaces for Musical Expression* (NIME '03), 208-210.
4. Attaiment Company. GoTalkNow. Retrieved August 3, 2018 from https://www.attainmentcompany.com/gotalk-now
5. Amal Dar Aziz, Chris Warren, Hayden Bursk, and Sean Follmer. 2008. The flote: an instrument for people with limited mobility. In *Proceedings of the 10th international ACM SIGACCESS conference on Computers and accessibility* (ASSETS'08), 295-296.
6. Chris Anderson. 2012. *Makers: The New Industrial Revolutions.* Crown Business, New York, NY.
7. Bela. Retrieved August 1, 2018 from http://www.bela.io/
8. Albert Bandura. 2006. Toward a psychology of human agency. *Perspectives on psychological science*, *1*(2), 164-180.
9. Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative research in psychology*, *3*(2), 77-101.
10. Kenneth Bruscia. *Defining music therapy*. Barcelona Publishers, New Braunfels, TX, 1998.
11. Leah Buechley, Mike Eisenberg, Jaime Catchen, and Ali Crockett. 2008. The LilyPad Arduino: using computational textiles to investigate engagement, aesthetics, and diversity in computer science education. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '08), 423-432.
12. CCRMA Satellite. Retrieved August 1, 2018 from https://ccrma.stanford.edu/~eberdahl/Satellite/
13. Foad Hamidi, Melanie Baljko, Toni Kunic, and Ray Feraday. 2015. A DIY Communication Board Case Study. *Journal of Assistive Technologies,* 9(4), 187-198.
14. Jiffer Harriman, Michael Theodore, and Mark Gross. 2015. The Kitsch-Instrument: Hackable Robotic Music. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction* (TEI '15), 141-144.
15. Jonathan Hook, Sanne Verbaan, Abigail Durrant, Patrick Olivier and Peter Wright. 2014. A study of the challenges related to DIY assistive technology in the context of children with disabilities. In *Proceedings of the 2014 conference on Designing interactive systems* (DIS'14), 597-606.
16. Kevin Huang, Jesse Smith, Kimberly Spreen, and Mary Frances Jones. 2008. Breaking the sound barrier: designing an interactive tool for language acquisition in preschool deaf children. In *Proceedings of the 7th international conference on Interaction design and children* (IDC '08), 210-216.
17. Amy Hurst, and Jasmine Tobias. 2011. Empowering individuals with do-it-yourself assistive technology. In *Proceedings of the International ACM SIGACCESS Conference on Computers and Accessibility* (ASSETS'11), 11-18.
18. Hyunjoo Oh, Jiffer Harriman, Abhishek Narula, Mark D. Gross, Michael Eisenberg, and Sherry Hsi. 2016. Crafting Mechatronic Percussion with Everyday Materials. In *Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction* (TEI '16), 340-348.
19. Seray B. Ibrahim, Asimina Vasalou, and Michael Clarke. 2018. Design Opportunities for AAC and Children with Severe Speech and Physical Impairments. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (CHI '18). Paper 227, 13 pages.
20. Sergi Jordà, Günter Geiger, Marcos Alonso, and Martin Kaltenbrunner. 2007. The reacTable: exploring the synergy between live music performance and tabletop tangible interfaces. In *Proceedings of the 1st*

international conference on Tangible and embedded interaction (TEI '07), 139-146.

21. Pedro Kirk, Mick Grierson, Rebeka Bodak, Nick Ward, Fran Brander, Kate Kelly, Nicholas Newman, and Lauren Stewart. 2016. Motivating Stroke Rehabilitation Through Music: A Feasibility Study Using Digital Musical Instruments in the Home. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (CHI '16), 1781-1785.
22. Miriam Konkel, Vivian Leung, Brygg Ullmer, and Catherine Hu. 2004. Tagaboo: a collaborative children's game based upon wearable RFID technology. *Personal Ubiquitous Comput*. 8, 5, 382-384.
23. Jeppe V. Larsen, Daniel Overholt and Thomas B. Moeslund. 2016. The Prospects of Musical Instruments for People with Physical Disabilities. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, 327-331.
24. Janice Light and Kathryn Drager. 2007. AAC technologies for young children with complex communication needs: State of the science and future research directions. *Augmentative and Alternative Communication* 23, 3: 204–216.
25. Wendy, L. Magee. 2006. Electronic technologies in clinical music therapy: A survey of practice and attitudes. *Technology and Disability*, 18, 3, 139-146.
26. Logan® ProxTalker® Modular. Retrieved August 3, 2018 from https://logantech.com/collections/proxtalker-and-proxpad-modular-communication-systems/products/proxtalker
27. Gareth B. Loy. Musicians Make A Standard: The MIDI Phenomenon. *Computer Music Journal,* 9, 4 (Fall 1985), 8-26.
28. MaKey MaKey toolkit. Retrieved August 1, 2018 from http://www.makeymakey.com/
29. Patrizia Marti and Liam J. Bannon. 2009. Exploring user-centered design in practice: Some caveats. *Knowledge, Technology & Policy,* 22 (1), 7-15.
30. Argyro Moraiti, Vero Vanden Abeele, Erwin Vanroye, and Luc Geurts. 2015. Empowering Occupational Therapists with a DIY-toolkit for Smart Soft Objects. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction* (TEI '15), 387-394.
31. Ajit Nath and Samson Young. 2015. VESBALL: a ball-shaped instrument for music therapy. In *Proceedings of the International Conference on New Interfaces for Musical Expression* (NIME'15), 387-391.
32. Yvonne Rogers, Jeni Paay, Margot Brereton, Kate L. Vaisutis, Gary Marsden, and Frank Vetere. 2014. Never too old: engaging retired people inventing the future with MaKey MaKey. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '14), 3913-3922.
33. P. Frazer Seymour, Justin Matejka, Geoff Foulds, Ihor Petelycky, and Fraser Anderson. 2017. AMI: An Adaptable Music Interface to Support the Varying Needs of People with Dementia. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility* (ASSETS'17)*,* 150-154.
34. John M. Schaefer and Natalie Andzik. 2016. Switch on the Learning: Teaching Students with Significant Disabilities to use Switches. *Teaching Exceptional Children*, 48(4), 204–212.
35. Sophie Skach, Anna Xambó, Luca Turchet, Ariane Stolfi, Rebecca Stewart, and Mathieu Barthet. 2018. Embodied Interactions with E-Textiles and the Internet of Sounds for Performing Arts. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction* (TEI '18), 80-87.
36. Sonic-Pi: The Live Coding Music Synth for Everyone. Retrieved January 19, 2018 from http://www.sonic-pi.net/
37. Katharina Spiel, Christopher Frauenberger, Eva Hornecker, and Geraldine Fitzpatrick. 2017. When Empathy Is Not Enough: Assessing the Experiences of Autistic Children with Technologies. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (CHI '17), 2853-2864.
38. Joshua G. Tanenbaum, Amanda M. Williams, Audrey Desjardins, and Karen Tanenbaum. 2013. Democratizing technology: pleasure, utility and expressiveness in DIY and maker practice. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '13), 2603-2612.
39. Brygg Ullmer and Hiroshi Ishii. 1997. The metaDESK: models and prototypes for tangible user interfaces. In *Proceedings of the 10th annual ACM symposium on User interface software and technology* (UIST '97), 223-232.
40. Katia Vega and Hugo Fuks. 2014. Beauty tech nails: interactive technology at your fingertips. In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction* (TEI '14), 61-64.
41. Barbara L. Wheeler and Kathleen M. Murphy. 2016. *Music Therapy Research* (3rd. ed.). Barcelona Publishers, New Braunfels, TX.
42. Ikuko Eguchi Yairi and Takuya Takeda. 2012. A music application for visually impaired people using daily goods and stationeries on the table. In *Proceedings of the 14th international ACM SIGACCESS conference*

on Computers and Accessibility (ASSETS '12), 271- 272.