Bishop BoomBox: A Physically Accessible Drum Machine

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Figure 1: The Bishop BoomBox, an 8-step, 4-track drum sequencer that activates steps either by physical touch or by positioning custom high-capacitance magnetic pieces.

ABSTRACT

This paper presents the design, aesthetic considerations, and technical details of the *Bishop BoomBox*, an innovative physically accessible drum machine and sequencer inspired by classic drum machines, golden-era Hip-Hop culture, and chess. The BBB features an 8-step, 4-track sequencer, with steps triggered through physical touch or the placement of custom high-capacitance "chess" pieces, which trigger capacitive sensors monitored by a *Bela* microcontroller. It provides volume, swing, tempo, and recording controls housed in a movable module. The BBB contains a rechargeable LiPo battery, detachable magnetic monitoring speakers, three-way toggles for per-track sample selection, and a custom stand designed to attach the device to the player's power wheelchair securely. The BBB was co-designed through 10 collaborative co-design sessions. Drawing influence from Crip kinship, Disabled joy and the aesthetics and poetics of interaction were emphasized as key design metrics, challenging conventional Disability design norms that have tended to focus on utility and usability.

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Author Keywords

Accessibility, Drum Machine, Capacitive Sensing, Disability and Access, ADMI

CCS Concepts

•Applied computing → Sound and music computing; •Human-centered computing → *Accessibility design and evaluation methods;* Accessibility technologies;

1. INTRODUCTION

This paper details the design process, aesthetic considerations, and technical details of the Bishop BoomBox (BBB), a physically accessible drum machine and sequencer inspired by classic drum machines, hip-hop culture, and chess. The BBB, as seen in Figure 1, consists of an 8-step, 4-track sequencer, and a movable control module. Notably, steps on the BBB can be triggered through either physical human touch or the placement of custom high-capacitance "chess" pieces onto each step, as the BBB uses capacitive sensing to trigger and monitor step states.

This project centered enjoyment as a key design metric, as opposed to other pragmatic design metrics often found in Disability-centered human-computer interaction (HCI) research, such as words per minute [16]. This focus on joy within the context of Disability design highlights tensions within traditional design for enjoyment (e.g. the design of toys, games, instruments, etc.), which generally assumes a non-Disabled user as the primary user group for artifacts of enjoyment [2], whereas canonical methodologies in Disability design focus on the *practical*, the *productive*, and the *useful*, with less attention paid to fun, enjoyment, and aesthetic experience [27].

Additionally, this project was influenced by Disabled solidarity/Crip kinship [12]. While May and McLeod have different lived experiences of Disability, the overlaps of Disability pride and acknowledgment of lived Disabled experience are present sites of knowledge throughout this project.

2. BACKGROUND & RELATED WORKS

2.1 Disability Design

Rosemarie Garland-Thomson highlights Disability as a body being in a two-way "misfit" relationship, running from the body to the external and back, as opposed to a strict tragedy that is to be overcome or a bodily/medical "defect" in need of curing [11]. Garland-Thomson's work therefore encourages us to ask the questions "what does disability *do*?" rather than "what *is* disability?" South African academic

Lieketseng Ned reexamines the construction of Disability through the lens of the African renaissance, specially focusing on the philosophy of Ubuntu as a framework through which the Western construction of Disability can be viewed in its relation to notions of capitalist productivity and the independence of the individual. Ubuntu, coarsely translated as "I am me through you," might suggest that Disability is a site of the breakdown of our inherent interdependence, rather than a denial of personal independence [23].

Stemming from this framing of disability as a socially and culturally contextual misfit relationship, the field of Disability Design can be seen as both the cataloging and creation of objects, systems, and experiences in which these misfits of disability are explored, navigated, highlighted, and bridged. Distinct from design frameworks that center designing *for* or *with* Disabled people, Disability Design actively includes Crip Technoscience, the situations in which Disabled people are designing and making for themselves, by themselves, or within and for their community, in addition to more traditional co-designing relationships with potentially non-Disabled designers from academia or industry [12].

2.1.1 Canonical Design Thinking

The design thinking process is often broken into discrete steps, namely "empathize, define, ideate, prototype, and test" [25]. Design thinking-based frameworks have generally generated problem- and need-centered design paradigms, with a strong focus on making and crafting [17]. Many design frameworks and paradigms contain some, if not all of these discrete steps, with each framework adding additional nuance and reorientation to this general outline [1]. This includes several design frameworks centered around users with disabilities.

A notable departure from canonical design thinking is **critical design**. Bardzell & Bardzell define critical design as "a research through design methodology that foregrounds the ethics of design practice, reveals potentially hidden agendas and values, and explores alternative design values" [1]. Put simply, critical design processes can seek to pose questions rather than attempt to primarily answer them.

2.1.2 Universal Design

Universal design, often credited to architect and wheelchair user Ronald Mace in 1985, is a design framework and movement that seeks to improve access to—and experiences of—environments, objects, and systems for people with disabilities, often stating that "accessible design is just good design," highlighting the positive effects that accessible designs often had for non-disabled folks [14]. Since its inception, universal design has often been associated with seven principles [28], namely:

1. **Low physical effort:** Can be used efficiently, comfortably, and with a minimum of fatigue.
2. **Size & space for approach & use:** Appropriate amounts of space are provided around the design to allow for use.
3. **Equitable use:** Meaningful and marketable to a diverse range of people, including those with disabilities.
4. **Flexibility in use:** Actively accommodates a wide range of abilities and use cases.
5. **Simple & intuitive:** Easy to understand with minimal reliance on previous experience.
6. **Tolerance for error:** Minimizing hazards and unwanted consequences as the result of unintended actions.
7. **Perceptible information:** Necessary information is communicated clearly and effectively to users of a variety of sensory abilities and in a variety of ambient conditions.

2.1.3 Inclusive Design

The framework of inclusive design grew slowly, emerging mainly in the UK during years of post-war collaborative work between researchers, designers, and industry partners [5]. Similar to universal design, it highlighted the many people that benefited from active consideration of disability during design, but with an additional focus on specific individuals and use cases, rendering these external benefits and issues of scaling generally of lesser concern. While this framework's principles are slightly less codified, *Microsoft* has published their interpretation of the framework [20] as follows:

1. **Recognize exclusion:** Acknowledge bias and actively recognize exclusions that happen because of mismatches between people and experience.
2. **Learn from diversity:** The fresh, diverse perspectives of people are the key to true insight.
3. **Solve for one, extend to many:** Everyone has abilities and limits. Many people benefit from products created for people with disabilities.

2.1.4 Other Disability Design Frameworks

Other schools of thought include regional variations of either universal or inclusive design, including barrier-free design, design for all, and equitable design. Some notable emerging design frameworks include adaptive or diffuse design, which "focus on augmentation and alteration on the entire ecology that is required to make the world more meaningfully accessible", encouraging system-wide, holistic considerations in the design process [14]. The advocacy-focused *Design Justice* movement seeks to more overtly center intersectionality of race, gender, sexual orientation, and class into the Disability design conversation [8] Finally, ability-based design seeks to design interactive systems that "focuses on people's abilities in context, on what people can do, rather than on what they cannot do;" for example, highlighting that a new technology was designed for people who read braille rather than saying the device is for people who are blind or low vision, assuming that braille reading is an inherent attribute of every person in that community [29].

2.2 Inclusive NIMEs

Accessible digital musical instruments (ADMIs) are instruments that center Disability and access in their design and use. In a 2019 review by Frid, 83 ADMIs were identified ranging from brain-computer interfaces, to physically accessible MIDI and gesture controllers, to augmented guitars [10, 13, 21, 19], highlighting the diversity of instruments and musical applications in the field of ADMIs. A recent example of an ADMI is Förster and Komesker's *LoopBlocks*, a collaborative, tangible step-sequencer using photoresistors in a wooden grid to trigger musical events [9].

While not designed with Disability and access as a central concern, electronic drums and sequencers have afforded many musicians with Disabilities access to new ways of musicking. For example, Rick Allen, the drummer of rock band *Def Leppard*, highlighted that the ability to map various sounds to different pedals and sensors on an electronic drum kit afforded him the ability to continue live rock drumming after a car accident and subsequent amputation of his left arm [6]. From the invention of the *Rhythmicon* in 1930, to the *Roland TR-808* and *Linn LM-1 Drum Computer* in 1980, to the *Akai MPC* in 1988, drum machines and sequencers have afforded users the ability to create rhythmic patterns and beats in a non-real-time manner and through different, smaller physical gestures compared to playing drum kits and other percussion instruments [24, 26].

2.3 Disability and Hip-Hop

Not only is Disability present in physically Disabled MCs and rappers such as Fetty Wap and *The Sugar Hill Gang's* Rob Da Noize Temple [7], and those exploring themes of mental and/or psychiatric Disabilities (e.g. Tyler, the Creator [15]), but also in the producers and composers who create riddims, beats, and backing tracks. In 2006, hip-hop pioneer and producer J Dilla composed his seminal album *Donuts* on an Akai MPC from a hospital bed while impaired by thrombotic thrombocytopenic purpura (TTP) [4]. The small form factor and sequencer-based workflow of the Akai MPC afforded Dilla the option to continue creating music from his hospital bed. A focus on Disability is also central to the work of Hip-Hop artist Leroy Moore, a key organizer behind *Krip Hop Nation*[1], a "worldwide association of artists with disabilities" that seeks to unite Disabled Hip-Hop artists globally, encouraging them to advocate for Disability justice through their music and art [22]. The design process of the BBB builds on the culture of Disabled Hip-Hop and Krip Hop through the use of canonical drum machine sounds and by extending the classic drum sequencer interaction to be more physically accessible.

3. METHODS

The creation of the Bishop Boom Box employed an inclusive co-design approach, combining the inclusive design focus on a single player/user with the tight collaboration of co-design. All design decisions were made through extensive open dialogue that empowered both parties to set design goals and values as well as brainstorm paths around technical limitations. The process comprised 10 co-design sessions that took place approximately once a month, focusing on ideation (S1), iterative prototype creation and evaluation (S2-7), and final artifact evaluation, documentation, and musicking (S8 – 10). S1 took place at a public park while S2-10 took place at McLeod's apartment. In each session, May would bring pre-constructed prototypes and modular components as agreed upon at the end of the previous session, and leave with them at the end, making physical or programmatic adjustments before the next co-design session, with the exception of the final session when the completed Bishop Boom Box was officially handed over to McLeod, the BBB's permanent owner.

3.1 Positionality

Lloyd May is a music technology and applied Disability studies researcher from Stanford University and identifies as Disabled with a chronic pain condition. Lateef McLeod is an anthropology and Disability studies researcher from the California Institute of Integral Studies and identifies as a black and disabled person with cerebral palsy who uses augmentative alternative communication (AAC) to speak. May and McLeod participated in the co-design process together.

Michael Mulshine is a composer, computer music researcher, and music technologist from Stanford University and identifies as non-Disabled. Mulshine served in the capacities of hardware co-designer and lead electronics and firmware engineer on this project.

4. DESIGN PROCESS

Figure 2: The stages of prototyping: (Top Left) Cardboard prototypes of the sequencer grid and control module, (Top Right) Foam-core prototypes of pieces with different handle shapes, angles, sizes, and weight, (Bottom Left) Four-step works-like cardboard prototype, and (Bottom Right) The final BBB housing without any buttons or ports.

The first co-design session (S1) focused on the ideation and exploration of several state-of-the-art devices including the *Xbox Adaptive Controller* [2], and the *Gestruments* [3] and *Koala Sampler* [4] tablet apps. After discussing various musical and aesthetic interests, a strong interest in hip-hop and beat-making became apparent. Classic drum machines from the 'golden era' of American Hip-hop such as the Roland TR-808 and the Akai MPC were of particular interest. The biggest decision to make at this stage was in relation to form and form-factor: should we make an app for a tablet (with easy setup and use) or create a custom, all-in-one, hardware-based instrument (with more control over visual aesthetics and poetics of interaction)? Hybrid options were briefly discussed but did not satisfy our personal aesthetic interests at the time. Ultimately the poetic and aesthetic possibilities of a physical, standalone device were prioritized over a tablet app.

S2 concretized some of the aesthetic interests, centering on the desire for a sequencer-style drum machine that afforded the option for non-real-time composition. The strong visual overlap of a grid sequencer and a chess board was noted, and McLeod highlighted chess as both a personal interest and a potentially fruitful source for poetic and gestural comparison. We discussed the possible samples the instrument could trigger and sequence and landed on kick/bass drum, snare, hi-hat, and clap/cow-bell as the four tracks of interest. The ability to easily switch the active sample on a track-by-track basis was highlighted as

[1] `https://kriphopinstitute.com/`

[2] `https://www.xbox.com/en-US/accessories/controllers/xbox-adaptive-controller`

[3] `https://gestrument.com/`

[4] `https://www.koalasampler.com/`

desirable, with a mix of classic electronic/synthesized drum samples being the sonic palette of interest. Following a short jam session using the *Koala Sampler* tablet app, we decided that switching between three samples per track would be sufficient given the diversity of desired sounds used during the jam.

S3 explored the form factor of a grid sequencer, using cardboard prototypes of a variety of sizes to determine the approximate maximum dimensions of the instrument, as well as how many steps in the grid sequencer were desired, ultimately landing on 8-steps and four instrument tracks. In line with chess idioms, we discussed that physical pieces would be placed on the sequencer grid to trigger steps, as opposed to the pressing of a button or the use of a screen for player feedback. The weight of the pieces was highlighted as an important factor that could afford increased control and ease of use once optimized. The use of magnets was also discussed as it could provide additional, stabilizing resistance to picking up the piece, and afford a level of useful "movement quantization" as the pieces could snap into place to aid in precision placement. We additionally discussed the *Xbox Adaptive Controller's* modular design, and how the modularity of the control unit would afford ease of movement through different configurations, actively accommodating and anticipating changes in comfortable movement ranges from day to day rather than incorrectly assuming the body and comfortable movement range of the player as a fixed constant.

The desired control and output configurations were also established, with the desire for an output jack for live performance with a PA system as well as both internal speakers and a headphone jack for other musicking situations. Additionally, it was also discussed that it would be highly preferable if the instrument could be comfortably playable from McLeod's powerchair.

S4 explored the form factor of the board, fine-tuning its possible size through cardboard prototypes, and introducing various possible designs chess piece designs (Figure 2). Pieces of various weights and magnet configurations were tested to determine the optimal weight (170g) and magnet placement (a small neodymium magnet placed in each corner of both the grid cell and piece, separated by 5mm of non-ferrous material). We discussed that it would be beneficial if the sequencer could be triggered by physical human touch or the pieces, to allow for a wider variety of interaction [18]. We opted for capacitive sensing as a touch-sensing mechanism, as it would afford scalable touch-based interaction that requires low physical effort and has no moving components that might be more likely to break.

S5 and S6 consisted of sessions fine-tuning the shape, height, and weight of the pieces, as well as improvised jamming with a functional 8-step cardboard prototype. Many of the prototype pieces broke while being handled, illustrating the clear need for sturdy pieces that could withstand energetic movement and handling in both the vertical and lateral directions. We additionally fine-tuned the sonic palette of the 4-tracks to incorporate samples that covered a wider range of drum sounds, such as the inclusion of acoustic kick and snare samples.

S7 was primarily used to jam with the functional, but not yet finalized, main housing, allowing for discussion around the optimal placement of the on/off toggle and resting positions of unused pieces. McLeod's partner was present for part of the session and highlighted how the instrument could be played collaboratively, informing the decision for the internal speakers to be reversible so that they could face either toward or away from the player, providing clearer feedback to collaborative players or to a small audience.

S8 and S9 consisted of jamming with the finalized sequencer unit and fine-tuning the placement and type of sliders and buttons used on the control unit, with rounded cubes found to be the most desirable shape. It was also clear through jamming that an additional wooden support that was able to comfortably hold both the sequencer and control box modules and rested securely on McLeod's tray was needed. S10 consisted of documentation, jamming, and reflection on the project, as well as handing over of all necessary components to McLeod.

5. THE BISHOP BOOMBOX

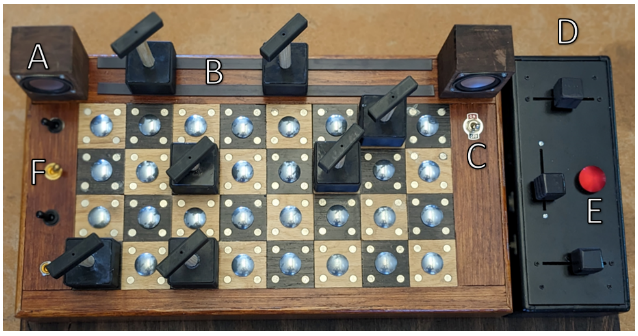

Figure 3: Diagram of the BBB with labeled components. (A) Speakers attached via magnets, (B) Magnetic strip for resting unused pieces, (C) On/Off toggle with LED light to indicate on and recording states, (D) Control box connected to the sequencer via ethernet cable with sliders to control volume, swing, and tempo, (E) A button to trigger recording state, and (F) Three-way toggles to select the sample played by each track of the sequencer.

5.1 Features

1. **4-track 8-step sequencing:** Users toggle sequencer steps on and off in 4 overlapping rhythmic tracks of 8 steps each

2. **Magnetic pieces:** Chess-like pieces can be used to toggle steps on and off. Magnets in the pieces help them snap into place for ease of placement and helpful resistance to steady one's hand. The handles are angled for easier one-handed gripping while seated without angling the wrist or pushing the elbow into the chest. The stems are of variable length to increase the ease of grip for pieces next to each other.

3. **Movable control module:** A separate detachable control module contains a button to toggle recording status as well as sliders that control high-level musical parameters, namely: swing, tempo, and overall volume.

4. **Sample selection:** Four 3-way toggle switches pick the sample used for each track.

5. **Magnetic detachable speakers:** Two magnetic monitoring speakers can be easily attachable/detachable to the top corners of the sequencer module. Each speaker can independently be placed facing toward or away from the primary player, affording both self-monitoring and sound sharing.

6. **Audio outputs:** Quarter-inch line output and headphone jack for external monitoring or recording.

7. **Recording:** A button on the control box allows users to record the audio output directly on the BBB and can be retrieved either via connection to a computer with a USB-cable, or by inserting a USB thumb-drive to the dedicated USB-A port before recording.

8. **Battery power:** The BBB is powered by an onboard, USB-C-rechargeable LiPo battery that can power the device for 1-2 hours. Additionally, if the battery is connected to a standard 5V 1A USB-C charger while being played, the BBB can run indefinitely.

9. **Re-programmability:** A dedicated USB-C port allows for access to the Bela, affording reprogrammability and firmware updates. If the co-creators desire to implement or amend certain features, the Bela can be reprogrammed via USB-C connection.

10. **Physical On/Off Switch:** An on-off switch to turn on and off the device, out of the way of motions in a typical use-case

5.2 Electronic Hardware and Firmware

To achieve the desired form factor and simplicity of use, the BBB was designed as a standalone sound-producing ADMI with minimal external reliance (e.g. on computers, external power supplies, or excess external cabling). May and Mulshine determined the hardware suite that was used, consisting of a Bela microcontroller and *Trill Touch Sensors*[5] (namely two *Trill Craft*[6] 30-channel capacitive breakout boards) for the core functionality of the drum sequencer. Other electronic hardware employed consisted of:

1. 1 LiPo battery and SparkFun 5V/1A Charger/Booster breakout board for wireless on-board power

2. 1 Adafruit 3.7W Stereo Amplifier (MAX98306) to power the magnetic speakers

3. 2 sturdy surface-mount ethernet ports and 1 short ethernet cable to communicate between the main drum sequencer and external control box

4. 1 surface-mount USB-A port for a USB thumb drive to store and access recordings. 2 surface-mount USB-C ports for charging or external powering and reprogramming.

5. 3 sliders with large 3d-printed caps for control of sequencer parameters Volume, Swing, and Tempo

6. 4 3-way toggle switches to select the current sample on a per-track basis

7. 1 large red push-button to toggle recording on and off

8. 1 RGB LED to indicate power on, off, and recording status

9. 1 toggle switch to power on and off

Mulshine used Pure Data and the web-based Bela IDE to set up communication between the Bela board and these peripherals and hardware and implement the various BBB features.

[5] https://bela.io/products/trill/
[6] https://shop.bela.io/products/trill-craft

5.3 The Capacitance Issue

The original BBB "chess" piece prototype consisted of a strip of copper tape enclosed in a cavity at the base of a 3D-printed box that housed magnets to latch onto each piece. However, copper tape alone did not register large enough differentials in capacitance to be reliable for use in the instrument's firmware. Fortunately, the Trill Craft touch sensors are easy to interface with, debug, and reconfigure via Pure Data and the Bela IDE. But even after fine-tuning the capacitance thresholds and taking care to configure each step's electrode similarly (e.g. via mounting mechanism and length of wiring), we failed to get large enough readings with these chess pieces (without human contact).

Realizing that the issue lay in the vast gulf in capacitance between human touch and the inanimate plastic chess pieces we created, we brainstormed methods of increasing the pieces' capacitance. Various approaches were tested, including increasing the size, amount of metal encased, surface area of metal, and placing magnets inside the pieces to increase contact with the sensor electrodes.

Whimsically drawing inspiration from DIY science heroes, the *Mythbusters*, we set out to create a material with human-like chemical attributes that could be encased in each piece, similar to the ballistics gel used in the *Mythbusters* show [3]. We created cubes of high-sodium ballistics-grade gelatin, combining salt, gelatine, and bleach to prevent fungal growth. We enclosed these in plastic with a bag sealer and encased them in our chess pieces. Delightfully, the addition of the salty gelatin cubes improved the capacitance readings by 2̃00% from the previous baselines and proved sufficiently reliable in toggling sequencer steps on the BBB, leading to the final "Jell-O Surprise" pieces.

5.4 Tutorial and Documentation

To preserve the longevity of the instrument, an instructional video was created to ensure that aides, friends, sound engineers, and any others who might be involved in musicking with the Bishop Boombox know how to set-up, operate, and correctly disassemble and pack the BBB.

Figure 4: (Left) The 1/4-inch line-out jack, a USB thumb-drive to save the recordings, and two USB-C ports for charging the battery (bottom) and updating the software (top), and examples of the final BBB pieces (right), consisting of a 3D-printed base filled with sterilized gelatin and magnets in each corner, a wooden stem, and 3D-printed rectangular handle angled diagonally.

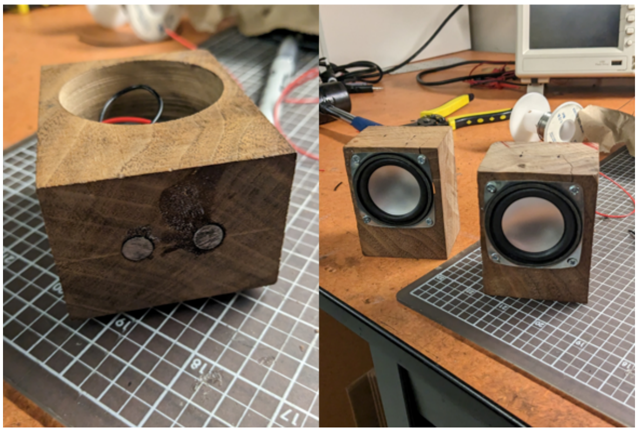

Figure 5: (Left) The two magnets placed at the bottom of each speaker served as both a way to snap the speakers into place and to conduct the signal. (Right) The completed speakers.

5.5 Reflection & Evaluation

After spending time musicking with the final BBB, McLeod reflected that the BBB is able to produce a variety of beats with an overall accessible user experience for someone who has cerebral palsy or another disability that limits one's motor control. In using the BBB, one could easily move the final BBB pieces to any of the magnetized places on the BBB steps to change the beat. The large endcaps on the sliders and the subtle resistance offered by the magnetized pieces and toggle switches improved the usability and accessibility of the device, as comparable devices often rely on highly controlled fine motor movements. Not only did the magnets afford an increased tolerance in the placement area through snapping, but the resistance this offered when removing a piece afforded a place to, for example, steady a shaky hand. McLeod highlighted that: "With the BBB pieces and controls so accessible, one can focus on what beat one can construct without worrying about how to use the device."

Following discussions about the BBB, several additional themes and affordances emerged, such as the opportunity for collaborative musicking, similar to *LoopBlocks* [9]. The BBB affords the option for one or more players to manipulate pieces or temporarily alter the sequencer through physical contact, by being opposite the primary player with the option to turn one or both magnetic speakers to face the additional players.

The poetics of the BBB's design and usage are tightly connected to Leroy Moore's *Kip Hop* [22] in the way it centers both Disability sensibilities (through its physically accessible design) and Hip-Hop homages (through the selected sonic palette and style of interaction). Additionally, the chess board pattern on the sequencer, combined with the use of the custom pieces on the grid, invites a closer reading of the overlap between the game of chess and the use of non-real-time instruments, such as sequencers and drum machines, by highlighting several factors often hidden in traditional performance, such as the forethought and planning behind non-real-time musical actions. The BBB's relatively large form factor, comprised of mostly highly varnished wood, shares more visual aesthetic similarities to wooden string instruments (violins, acoustic guitars, etc.) than it does to other drum machines or sequencers which are traditionally housed in sleek plastic or metal enclosures. This highlights the bespoke nature of the BBB, meticulously co-designed for a single person as opposed to a product destined for mass distribution, as well as showcasing that accessible musicking practices are also worthy of time, attention, and resources, and do not always have to be contained and constrained by iPads, 3D-printed custom MIDI controllers, or after-market adaptions to existing instruments. This is not to say those practices are in any way less engaging, worthy, innovative, or transgressive – quite often they are the most engaging options – but rather to highlight that the BBB may offer a different aesthetic point of comparison for future ADMI projects.

Lastly, the BBB is an example of an instrument and design artifact created through a joy-centered Disability design framework that highlighted the importance of poetic and aesthetic concerns alongside those of usability. The overt acknowledgment of this framework throughout the project influenced the design process by, for example, encouraging frequent jamming and musicking, playing videogames together with various adaptive controller configurations, and allowing space for more whimsical problem-solving strategies such as putting salty gelatine in the BBB's pieces.

6. CONCLUSIONS & FUTURE WORK

This paper details the design process and features of the Bishop BoomBox, a physically inclusive 8-step, 4-track drum machine consisting of a sequencer grid module, a controller module, and 20 high-capacitance pieces. Additionally, this project used a joy-centered inclusive co-design approach to ensure that aesthetic desires were foregrounded alongside usability and pragmatic considerations, and that lived experience and traditional design knowledge held comparable weight in all decision-making.

Future work could include the investigation of a hybrid system where a custom, physically accessible and aesthetically desirable custom MIDI controller is created to control software with increased technical capabilities such as *Koala Sampler*, thereby circumventing some of the current limitations of the BBB such as a limited sound palette.

7. ETHICAL STANDARDS

Funding for this project was obtained from internal grants from Stanford University. All researchers were informed, willing participants in the project with no financial conflicts of interest. The project was completed in compliance with Stanford University ethics guidelines. Participation in the project was voluntary throughout the entire process.

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