The Longevity of Bespoke, Accessible Music Technology: A Case for Community

Alex Lucas
Sonic Arts Research Centre
4 Cloreen Park
Belfast, BT9 5HN
alucas02@qub.ac.uk

Dr. Franziska Schroeder
Sonic Arts Research Centre
4 Cloreen Park
Belfast, BT9 5HN
f.schroeder@qub.ac.uk

Dr. Miguel Ortiz
Sonic Arts Research Centre
4 Cloreen Park
Belfast, BT9 5HN
m.ortiz@qub.ac.uk

ABSTRACT

Based on the experience garnered through a longitudinal ethnographic study, the authors reflect on the practice of designing and fabricating bespoke, accessible music technologies. Of particular focus are the social, technical and environmental factors at play which make the provision of such technology a reality. The authors make suggestions of ways to achieve long-term, sustained use. Seemingly those involved in its design, fabrication and use could benefit from a concerted effort to share resources, knowledge and skill as a mobilised community of practitioners.

Author Keywords

Abandonment, Access, Accessible, ADMI, AMT, Assistive, Bespoke, Community, Disability, Inclusion, Longevity.

CCS Concepts

•Applied computing → Sound and music computing; •Human-centered computing → Accessibility theory, concepts and paradigms; •Software and its engineering → Collaboration in software development;

1. INTRODUCTION

The commercial music technology sector is rife with tools to assist users in their creative pursuits. For instance, machine learning algorithms assisting remix artists in music source separation [8], or FFT analysis combined with gamification techniques, assisting musicians in learning their instruments[1]. Some people face disabling barriers in *musicking*, i.e. participation, in any capacity, in musical performance or composition [18]. Access barriers can be overcome through the use of commercial Accessible Music Technology (AMT) devices, such as Soundbeam[2]. As disability is often unique to an individual, bespoke technological solutions hold great potential to address specific needs.

In order for technology to be successful in removing access barriers, certain social, technical and environmental factors need to be considered. Unfortunately, it is often the case that bespoke AMT does not see sustained use [17]. Device longevity is also problematic for new digital musical instruments (DMIs) [10] and assistive technologies; studies have found that users abandon up to 50% of assistive technologies within five years [13]. The authors' underlying assumption is that factors contributing toward the short life-span of these two types of technology are likely to be compounded for bespoke AMT.

The Drake Music Project Northern Ireland (DMNI) is one of several third-sector inclusive music organisations that use music technology to provide disabled people with access to musicking. Other prominent organisations include Share Music & Performing Arts[3], Heart n Soul[4] and the OHMI Trust[5]. The primary author of this paper spent two years working as an Access Music Tutor with DMNI, developing bespoke AMT. Based on his experience this paper explores key factors affecting the adoption and longevity of bespoke AMT and suggests ways in which to achieve sustained use.

2. TERMINOLOGY

The term *Assistive Technology* describes technology, designed to assist disabled people in various aspects of their daily life. Screen reading software or computer access switches are examples of assistive technology. Some prefer the term *Accessible Technology*, arguing that all technology can be said to assist its users to some extent [9].

Accessible Digital Musical Instruments (ADMIs), rather than *Assistive Digital Musical Instruments*, is a term that is gaining popularity, especially within the NIME community. A shortcoming of this term is the omission of accessible or enabling technological tools, used for musical purposes, which are not necessarily musical instruments in their own right. The Haptic Wave [19] is an example of such technology, designed for audio engineers with visual impairments; it provides a physical representation of audio waveform amplitude. Another example is Device One[6], a USB MIDI switch interface, pictured in Figure 1. Developed in a collaboration between DMNI and the primary author, it allows control of music software by computer access switches. To include technology of this kind, the authors have opted for the term *Accessible Music Technology* (AMT). Furthermore, as such technology could be operated by a musician, composer or engineer the term *artist* is used to encompass all three.

Do-It-Yourself Assistive Technology (DIY-AT), is a term used to describe bespoke, accessible technologies. Often, the development of DIY-AT is done on behalf of the intended user, making it a misleading term. Past research has offered *DIY-for-others* as an alternative [12]. However, in being

[1] https://yousician.com/
[2] https://www.soundbeam.co.uk/
[3] http://sharemusic.se/english/
[4] https://www.heartnsoul.co.uk/
[5] https://www.ohmi.org.uk/
[6] https://github.com/alexmlucas/d1

NIME'20, July 21-25, 2020, Royal Birmingham Conservatoire, Birmingham City University, Birmingham, United Kingdom.

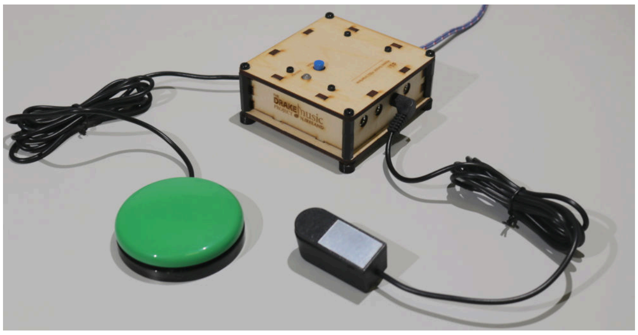

Figure 1: Device One (d1): DMNI Access Switch USB MIDI Interface.

somewhat of a misnomer, the authors have instead opted for the term *bespoke AMT*.

3. ACCESS BARRIERS TO MUSICKING

The Social Model of Disability [21] describes disability as a condition that arises through the organisation of society, the attitudes it holds and the design of the environment in which it exists. A person is disabled by factors external to them, not by any particular impairment. A typical example of this phenomenon is a wheelchair user, disabled from entry to a public building through the omission of a mobility ramp. In this scenario, we can say that the person in question faces an *access barrier*. There are many potential access barriers to musicking, dependent on the specific task or activity the artist is aiming to achieve and the nature of their impairment. The complexities of overcoming access barriers become clear when examining specific examples.

3.1 The Piano and The Wheelchair

In the context of musical performance. there is a requirement for musicians to have precise motor control. The piano in a traditional setting is a useful example. Disregarding its extraordinary inner workings, one might argue that the keyboard *interface* is conceptually simplistic, a series of keys each producing a different pitch when pressed. Early interactions with a piano involve the novice player becoming proficient in targeting specific keys with specific fingers of one hand. Before long a second hand is introduced. The player is soon using several fingers to press several different keys simultaneously and rhythmically. The keyboard interface demands a set of affordances which may not be available to individuals with physical impairments, for example, Cerebral Palsy, a life-long condition affecting movement and coordination [11].

The physical characteristics of the acoustic piano place requirements on the player. The keyboard mechanism is at a fixed height; it cannot move higher or lower. Convention dictates the player be seated on a specifically designed stool. Their knees must be beneath the keyboard mechanism, feet in reach of the pedals and arms extended forward with fingers resting on the keys. Figure 2 depicts the average dimensions of an adult seated in a wheelchair [7] alongside the approximate dimensions of a Yamaha U3 acoustic piano. On average a wheelchair armrest is 78cm from the floor. The top of the U3 keys are 73.5cm from the floor; this may hinder the wheelchair user from getting suitably close to the piano keys. The comfortable reach of an adult wheelchair user is approximately 18cm [6]. Although somewhat of a generalisation, these factors could result in a wheelchair user playing the piano in an uncomfortable position or prohibit them from playing the instrument entirely.

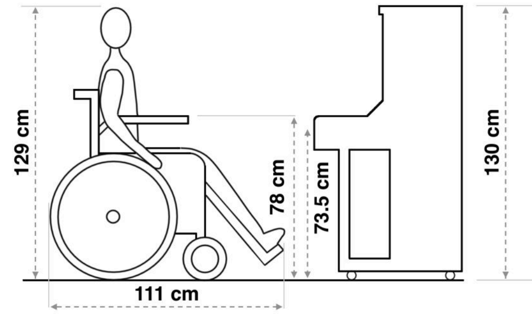

Figure 2: Typical Dimensions of an Adult Wheelchair User Alongside Dimensions of a Yamaha U3 Acoustic Piano.

How does an individual, with interest in playing and learning a musical instrument, overcome disabling barriers such as the fixed dimensions of an acoustic piano? Part of the disabling barrier in the above example lay in the design of the instrument and wheelchair technologies. These designs combined are imposing requirements on the musician. Therefore, theoretically, the barrier itself can be partially lifted through design. However, the critical challenge in overcoming access barriers lies not solely in conceptual design, but in its realisation, and application in a real-world context.

4. AMT LONGEVITY IN NORTHERN IRELAND

The majority of bespoke AMTs developed by DMNI are a result of short-term collaborative projects, such as hackathons, involving disabled artists, Access Music Tutors and makers. In 2015, the first of these events saw music technology students from Queen's University Belfast partnered with DMNI artists [16]. Over three days, each pair collaboratively designed and fabricated bespoke AMT tailored toward the music access requirements of the artist. Disabled artist Mary-Louise McCord co-designed a gestural instrument. Hand movements were captured and translated to sound using custom software and hardware.

Due to the success of the hackathon, organisers planned a second event the following year. Recognising the creative potential of the bespoke AMT she co-designed a year prior, Mary-Lousie decided that she would like to continue working on it. Unfortunately, this bespoke AMT no longer existed. The hardware had been dissembled and the software lost. To develop the concept further, Mary-Lousie would need to start from scratch. It seems like a waste of precious time and resources to be required to reinvent the wheel. Unfortunately, there is a shortage of longitudinal studies into the broader use of bespoke AMTs [5]. As both Assistive Technology and new DMIs face issues with longevity [13] [10], our assumption is the short life-span of bespoke AMT is likely a pervasive issue, affecting inclusive music organisations more widely.

To help better understand factors which contribute toward the sustained use of bespoke AMTs, the authors designed an ethnographic study. In similar fashion to past hackathons, a DMNI artist would co-design a bespoke AMT. In this instance the study would take place over six months, providing an opportunity to monitor longer-term use of bespoke AMT. The study was divided into three stages, as listed below, each stage two months in duration. The study commenced in the Autumn of 2018.

1. **Participatory Design:** An iterative process, seeing prototypes fashioned, tested with the artist and refactored.
2. **Development:** Technical work resulting in bespoke AMT fabrication.
3. **Usage:** Direct observation and artist diaries monitor the use of the bespoke AMT.

4.1 Participatory Design

The Human Activity Assistive Technology model (HAAT), is an approach credited with reducing the likelihood of abandonment due to poor design [1]. Prudence led to the application of this model to the ethnographic study. The HAAT model dictates that for accessible technology to be effective, we must consider the following four interconnected facets:

1. **Human:** What are the goals, skills and abilities of the artist?
2. **Activity:** What is the nature of the planned activity?
3. **Technology:** What features does it have, and how does one interact with it?
4. **Context:** What are the physical, social and cultural attributes of the environment in which the three elements above exist?

Stage 1 of the study was pivotal in providing the primary author with a robust understanding of all four areas. It is essential to note an early lesson at this point. It can take time to understand the subtleties of access barriers. Stage 1 of the study did not take two months as initially planned, it took closer to six. Below we share the critical findings of this process. The interconnected nature of the four facets of the HAAT model becomes evident when attempting to describe each in isolation.

4.1.1 The Human - The Artist

The disabled artist invited to participate in this study was Eoin Fitzpatrick, an attendee at weekly DMNI music workshops since 2016. Eoin, aged 32, has an eclectic taste in music, ranging from classic rock, through to Drum and Bass. Eoin is a member of Wired Ensemble, an electronic music outfit consisting of four disabled artists. Together, ensemble members share the goals of composing and performing original electronic music.

Eoin is a physically disabled wheelchair user. As in the above example, Eoin is disabled from playing traditional musical instruments. At the beginning of the study, Eoin was primarily using two gestures for musical interaction, identified by DMNI Access Music Tutors and Eoin's family through trial and error. The first gesture consists of Eoin moving his left forearm across an approximate range of 45 degrees, from the armrest of his wheelchair, to his chest. Eoin would brush his left knuckle across the screen of a face-down iPad, mounted on a microphone stand, controlling music Apps such as ThumbJam[7]. A shortcoming of this mode of interaction is that Eoin cannot see the graphical user interface of the Apps he is using. The second gesture is that of Eoin moving his head from side to side. Eoin's comfortable resting position is with his head tilted down, towards the left. Eoin can move his head from this position around to the right by approximately 90 degrees. Eoin's mother fashioned a seamed cap featuring a frontal pocket into which an iPhone would sit. Via the App GyroSynth[8], positional data transmitted wirelessly as MIDI messages would trigger virtual instruments in Ableton Live[9].

4.1.2 The Activity

Eoin wanted to play electric rhythm guitar. To help the authors understand his goals, Eoin participated in initial design-thinking exercises, for example, the creation of a mood board. Eoin's goals were captured in *user stories* and *use cases*, a typical approach utilised by user experience designers to guide the design and subsequent development process. Eoin's user stories include the two examples below.

> "As a musician, I would like to perform with electric guitar sounds in a live environment. I must be in control of my instrument when performing, and it must be comfortable for me to play."

> "As a composer, who works on new material regularly, I want my instrument to be relevant and applicable to the music I am composing. I want the instrument to integrate into my workflow."

4.1.3 The Technology

Eoin and the authors made an early decision to use digital technology to recreate the sound of the electric guitar to reduce cost and potential mechanical complexity. The authors assumed that Eoin's left arm and head gestures would be the best way for Eoin to play his instrument and therefore explored these first. Intertial measurement sensor (IMU) breakout boards using an InvenSense MPU-6050[10], were attached to a headset and wristband worn by Eoin. The authors discovered that while Eoin can move his head across a range of 90 degrees, it is difficult for Eoin to keep his head fixed once he had moved away from his natural resting position. Furthermore, Eoin demonstrated a tendency to move his head back to its resting position when moving his arm. Alternative controllers were tested, such as a sip/puff switch, using an NXP 5500DP pressure sensor[11]. As Eoin would typically drink through a straw, sipping came very naturally to him. Puffing was challenging for Eoin; he would be inclined to puff rapidly, sipping in-between puffs.

The authors explored ways of providing Eoin with visual feedback. An OLED display was attached to the IMU headset and used to display chord symbols. Research suggests disabled people have lower rates of literacy that non-disabled people [20]. The authors soon discovered they had incorrectly assumed that Eoin was literate, making this approach non-viable.

While there were caveats in the use of the interface elements described above, it was necessary to the authors to remember that given the opportunity, through practise, Eoin had the potential to acquire new manual skills and knowledge. Over-time, any dedicated musician may develop manual skills as an instrumentalist, and acquire musical knowledge; muscles can strengthen, sight-reading can improve. The same is true of Eoin, and his bespoke guitar.

The design matured iteratively into a standalone device with internal speakers that became known as Instrument One (i1) as shown in figure 3. Together, Eoin and the primary author decided not to use an IMU to track head movement. Instead, more accessible to Eoin, was the use of an off-the-shelf access switch. Eoin operates the switch with his chin to select, in a round-robin fashion, one of three preconfigured chords. Eoin is given visual feedback to which chord is selected through the use of multi-coloured LEDs. The authors found that Eoin can move his right-arm across a broader range, and is more consistent in its movement in

[7] https://thumbjam.com/
[8] https://www.beepstreet.com/ios/gyrosynth
[9] https://www.ableton.com/en/
[10] https://invensense.tdk.com/products/motion-tracking/6-axis/mpu-6050/
[11] https://www.nxp.com/docs/en/data-sheet/MPX5500.pdf

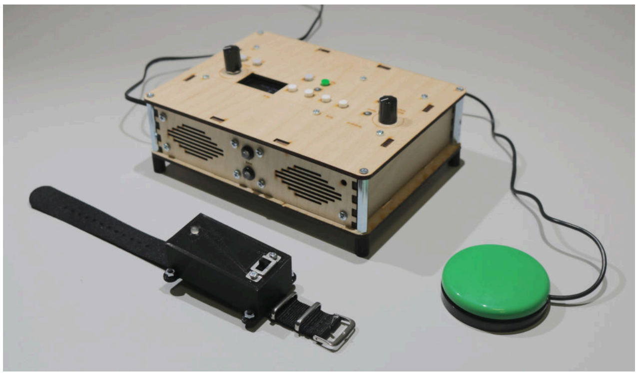

Figure 3: Instrument One (i1): A Standalone Virtual Guitar Instrument

comparison to his left-arm. A wristband on Eoin's right-arm transmits positional pitch data, wirelessly to the base unit of i1, enabling Eoin to pluck the strings of his virtual guitar. i1 is also capable of playing backing tracks, loaded via a USB memory stick.

4.1.4 The Context

Eoin was keen to be able to use his instrument not solely in DMNI music workshops but also at home, allowing him to practise his instrument and develop as an artist. Eoin's dad Peter, a digital immigrant [14], is one of Eoin's primary carers. When Eoin uses technology at home, for example when listening to audio-books via an mp3 player, its use is facilitated by Peter. The prospect of facilitating the use of bespoke AMT was daunting for Peter. The authors involved Peter in the participatory design process to help understand the carer's requirements as well.

During DMNI workshops, Access Music Tutor Daniel Todd facilitates the use of music technology. While Daniel is an adept music technologist, he does not have experience in software development or electronics. We needed to build enough flexibility into the device to ensure that the instrument could also meet Daniel's requirements, without the need to refactor code. Simultaneously the authors attempted to shield Peter from the relative complexity of the functions and features Daniel required. Consideration of the broader context of use resulted in the inclusion of Daniel and Peter as additional *humans* in the HAAT model. We, therefore, conducted user experience tests with both Peter and Daniel to improve usability and created user stories and use cases to capture their goals and requirements.

4.2 Development

At first glance, commercial AMT can seem expensive, perhaps understandably as niche products cannot benefit from cost reductions gained through economies of scale. At the outset of this study, it seemed as though a Raspberry Pi Zero[12], priced at a mere £4.50, could provide the functionality Eoin, Peter and Daniel required. In reality, technical design decisions made by the primary author, intended to expedite the development process, placed additional demands on the hardware. High-level open-source Python libraries were adopted to gain access to Bluetooth, Audio and GPIO functionality. Ultimately a RPi 3 Model A+[13], priced at £35 provided enough processing power to use these libraries simultaneously with acceptable latency. While not a significant increase in itself, this was the beginning of spiralling costs. To meet use case requirements, off-the-shelf breakout boards provided high-quality audio output and amplification. A Teensy LC[14] microcontroller board scanned the user-interface and displayed information on an Adafruit 1.3" Monochrome OLED screen[15].

The IMU breakout board mentioned above proved to be quite unreliable, producing inconsistent readings. A great deal of development time was lost troubleshooting. This breakout board was remarkably cheap; after some consideration, the primary author began to suspect that it was using a counterfeit sensor. An Adafruit BMO055[16] was a sophisticated, albeit more costly replacement. When coupled with an Adafruit Bluefruit M0 LE[17] microcontroller board, implementation of the wireless wristband was uncomplicated.

The development stage was expedited further by using an off-the-shelf access switch plus wheelchair mounts for the access switch and the base unit of i1. While cost can be reduced developing such items from scratch, there are time implications in this approach. The authors were keen not to rush the development stage of the study as in doing so there was a danger of accruing unnecessary technical debt [4]. It took approximately six months to develop i1, four months longer than initially planned. Ultimately there was a relationship between ease of development and material cost, the latter totalling £330. As a result of the development process the primary author realised that while the manner in which Eoin interacts with i1 is bespoke, many of the underlying technologies are not. The breakout boards, open-source code libraries and new code under-the-hood of i1 are likely to be useful in other bespoke AMTs.

4.3 Usage

A demonstration, given before hand-over, provided Eoin, Peter and Daniel with an overview of i1's features and functionality, providing an opportunity for questions. The authors produced a short manual, covering basic and advanced operation. As the study progressed, Peter needed further support to understand certain functions, such as how to play backing tracks, suggesting some usability issues remained. Danny demonstrated a higher degree of confidence in the facilitation of i1. However, he struggled with implementation quirks such as the file format and folder hierarchy requirements of the USB memory stick, used for backing tracks. Over time, Peter's confidence and abilities grew, resulting in him becoming the expert facilitator in the home environment. However, when Peter was not available, Eoin was not able to use i1; other carers did not have the requisite knowledge to facilitate its use.

Eoin consistently used i1 at least twice a week at home, during the majority of weekly DMNI workshops and at one public-facing performance[18]. Multi-track recording techniques were used in DMNI workshops to capture solo phrases, often played over ostinatos or short chord progressions. Eoin would practise his improvisation techniques at home over original DMNI recordings. During the two-month period in which Eoin used the instrument, both the primary author and Danny noticed improved control in Eoin's arm and head movements, albeit anecdotally.

[12] https://www.raspberrypi.org/products/raspberry-pi-zero/
[13] https://www.raspberrypi.org/products/raspberry-pi-3-model-a-plus/
[14] https://www.pjrc.com/teensy/teensyLC.html
[15] https://www.adafruit.com/product/938
[16] https://learn.adafruit.com/adafruit-bno055-absolute-orientation-sensor
[17] https://www.adafruit.com/product/2995
[18] https://www.youtube.com/watch?v=gYGuIXm8OBA&feature=youtu.be

The authors expected to perform maintenance on i1 during its use; fixing bugs, hardware faults and adding features. And that a failure to perform maintenance would potentially have a detrimental effect on the life-span of i1. Interestingly neither Eoin, Peter or Daniel reported or complained of any issues. The primary author recorded one hardware fault (a loose screw!), and a single software bug which caused an error in parameter values displayed. Daniel suggested one feature; being able to adjust the release-time of the guitar's amplitude envelope.

Through observation, new use cases occurred to the primary author. For instance, on some days, Eoin's arm movements could be more restricted. Providing facilitators with a way to easily adjust the range of movement required to trigger the six guitar strings would add useful flexibility. It's unclear at this stage if maintenance requests would originate from Eoin, Peter and Daniel if they were using the instrument independently without regular contact with the primary author. Despite the small number of new feature ideas, due to time constraints, the primary author could not expand the feature set during this phase of the study. Altogether Eoin enjoyed using his instrument during these two months and intends to continue using it in the future.

5. DEPENDENCY MODEL OF ACCESSING MUSIC THROUGH TECHNOLOGY

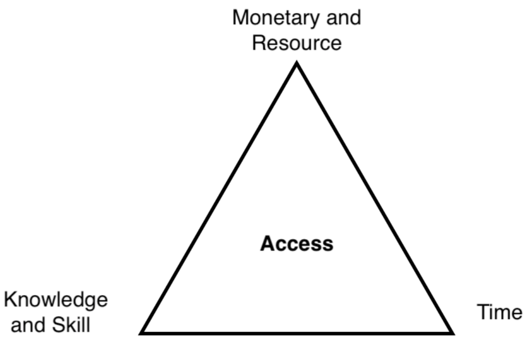

Figure 4: The Dependency Model of Accessing Music Through Technology.

Through the development of Eoin's instrument, the authors realised that there were dependencies which made access to music through technology a reality for Eoin. These were *monetary and resource*, *knowledge and skill* and *time* as depicted in figure 4. Such dependencies are interconnected. For example, access to ample off-the-shelf resources can result in access barriers being lifted quickly for an individual. While these three dependencies are somewhat pervasive in the development of new music technology, it is essential to draw attention to them in the context of inclusive music to avoid assumptions being made that as low-cost maker technology has the potential to remove access barriers, this will naturally happen as a matter of course.

5.1 Monetary and Resource Dependencies

In order to use technology to remove an access barrier, such a resource needs to be available to the person facing the barrier, or they must have the means to acquire it. Eoin gained access to bespoke AMT through the case study described above. It is essential for academics involved in similar studies to consider how a participant might gain long-term access to an enabling device outside the confines of a study. Eoin has regular access to commerical AMT through DMNI workshops. Soundbeam is one of the most prominent commercial AMT devices. At an entry price of £2500[19], Soundbeam is likely beyond the financial means of many disabled people within the UK [3]. Financial barriers may result in relatively few disabled people owning AMT, using devices at home and practising technique, as would a player of a traditional instrument.

5.2 Knowledge and Skill Dependencies

A degree of specialist knowledge and skill is required to utilise music technology to remove access barriers. In Eoin's case study, knowledge and skill dependencies existed at two tiers; in the facilitation of music technology, and in its technical development. Facilitators may not necessarily possess the technical knowledge and skill required to develop and maintain bespoke AMT, but will likely have a strong understanding of the artists they work with, their goals and the access barriers they face in musicking. It's vital for all stakeholders involved in the use of bespoke AMT to share knowledge through participation in the design process.

5.3 Time Dependencies

On a practical level it takes time to develop technology; to write code and design circuits. In addition, it takes time for the maker to familiarise themselves with the artist and understand the requirements they might have of bespoke AMT. To aid facilitators, ease-of-use was of crucial importance in i1. Tesler's Law of *The Conservation of Complexity* states that a degree of complexity is inherent in a process [15]. Makers need to decide how to distribute complexity between a user interface and the underlying system, which can often be a time-consuming affair.

6. COMMUNITY

The Social Model of Disability seeks to avoid a paternalistic view where disabled people are framed as in need of help and requiring support from others. The reality of digital technology use in a broader context is that any user, regardless of disability, might require support from others. For instance, when faced with a usability issue, or as a result of experiencing a software bug or hardware fault. Companies involved in the manufacture of music technology products and services support their users through dedicated technical support teams with maintenance tasks factored into the schedules of engineers. Just like the primary author, independent makers may struggle to find the time to work on the maintenance of bespoke AMTs and support their use. There is one potential solution to this, that of collaborating with others in such projects.

e-NABLE[20] is an online community, totalling some 3300 volunteers, dedicated to the design, fabrication and provision of low-cost 3D-printed prosthetics. The collaborative efforts of designers, engineers and occupational therapists have resulted in sophisticated, standardised designs, capable of accommodating the needs of individual users through customisation. The motivations of e-NABLE volunteers include that of learning new skills coupled with a desire to have a positive impact on others [12]. The number of e-NABLE devices distributed to date is approximately 800 [12]. How could a maker be encouraged to contribute toward the maintenance of a bespoke AMT such as Eoin's? One might assume that an individual looking to volunteer their time to project might be interested in helping the largest number of people possible in the allotted time, a concept known as effective altruism [2].

[19]`https://www.soundbeam.co.uk/new-page-3`
[20]`http://enablingthefuture.org/`

There is an opportunity to standardise and modularise the common underlying technologies of bespoke AMTs. John Kellys' bespoke guitar the Kellycaster[21] uses a sophisticated and comprehensive chord dictionary, which the primary author plans to implement in i1. Reuse of high-quality modular technical resources will likely improve the development ease of bespoke AMTs. Following a modular structure in hardware, software, and coding procedures can make it easier to fix, update and expand DMIs [10]. If several people are using one particular technology, makers may be more inclined to contribute their time towards its maintenance. Initiatives such as Drake Music England's DMLab[22] could play a vital role in connecting the somewhat disparate makers of bespoke AMT in a similar way to e-NABLED. Ultimately, the sharing of resources, knowledge and skill between artists using bespoke AMT, facilitators and makers will result in our collective musical landscape becoming richer from the inclusion all artists regardless of disability.

7. SUMMARY

The authors have described how bespoke AMTs are vital in enabling disabled artists to gain access to musicking, due to the unique way in which disability can present itself. There are dependencies at play which make the successful design, fabrication and use of such technology a reality. There are difficulties in achieving the sustained use of bespoke AMTs. The HAAT model can help makers nurture an understanding of the users of bespoke AMTs (i.e. artists, facilitators and makers), and its environmental context. To achieve the sustained use of bespoke AMT, the provision of technical support and ongoing maintenance is required. Rather than following an industry model of *service-based* support, makers and those involved in the use of bespoke AMTs will likely benefit from the formation of a community of practice. Such a community could work toward common goals through the sharing of resources, knowledge and skill, forming a participatory element of the broader musicking ecology.

8. ACKNOWLEDGMENTS

The authors of this paper would like to thank the Drake Music Project Northern Ireland for their continued support and the Arts and Humanities Research Council (AHRC) for funding this research.

9. REFERENCES

[1] A. M. Cook and J. M. P. N. J. Livingston. Need- and task-based design and evaluation. In M. M. K. Oishi, I. M. Mitchell, and H. M. Van der Loos, editors, *Design and Use of Assistive Technology*, chapter 3, pages 41–48. Springer, 2010.

[2] T. C. for Effective Altruism. Introduction to Effective Altruism. `https://www.effectivealtruism.org/articles/introduction-to-effective-altruism/`, 2020. Accessed: 25-04-2020.

[3] D. for Work and Pensions. Disability facts and figures. `https://www.gov.uk/government/publications/disability-facts-and-figures/disability-facts-and-figures`, 2014. Accessed: 10-01-2020.

[4] M. Fowler. Technical Debt. `https://martinfowler.com/bliki/TechnicalDebt.html`, 2019. Accessed: 10-01-2020.

[5] E. Frid. Accessible digital musical instruments — a review of musical interfaces in inclusive music practice. *Multimodal Technologies and Interaction*, 3(3), 2019.

[6] D. Hitchcock, M. Hussey, S. Burchill, and M. Galley. Making transport accessible for passengers and pedestrians, 2005.

[7] D. Hitchcock, M. Hussey, S. Burchill, and M. Galley. A survey of occupied wheelchairs and scooters, 2006.

[8] P. Kirn. Deezer's Spleeter is an open source AI tool to split stems, for remixes or . . . karaoke? `https://cdm.link/2019/11/deezers-spleeter-open-source-ai-tool-to-split-stems/`, 2019. Accessed: 10-01-2020.

[9] R. E. Ladner. Accessible technology and models of technology. In M. M. K. Oishi, I. M. Mitchell, and H. M. Van der Loos, editors, *Design and Use of Assistive Technology*, chapter 3, pages 25–31. Springer, 2010.

[10] F. Morreale and A. McPherson. Design for longevity: Ongoing use of instruments from nime 2010-14. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 192–197. Aalborg University Copenhagen, 2017.

[11] NHS. Cerebral Palsy Overview. `https://www.nhs.uk/conditions/cerebral-palsy/`, 2017. Accessed: 10-01-2020.

[12] J. Parry-Hill, P. C. Shih, J. Mankoff, and D. Ashbrook. Understanding volunteer at fabricators: Opportunities and challenges in diy-at for others in e-nable. In *CHI Conference on Human Factors in Computing Systems*, page 6184–6194. Association for Computing Machinery, 2017.

[13] B. Phillips and H. Zhao. Predictors of assistive technology abandonment. *Assistive Technology*, pages 36–45, 1993.

[14] M. Prensky. Digital natives, digital immigrants. *On the Horizon*, 9(5), October 2001.

[15] D. Saffer. *Designing for Interaction: Creating Innovative Applications and Devices*. New Riders, Berkeley, California, 2010.

[16] K. Samuels and F. Schroeder. Performance without barriers: Improvising with inclusive and accessible digital musical instruments. *Contemporary Music Review*, 38(5):476–489, 2019.

[17] K. Samuels, F. Schroeder, and F. Magowan. *Enabling Creativity: A study of inclusive music technology and practices at The Drake Music Project Northern Ireland*. PhD thesis, Queen's University Belfast, 2016.

[18] C. Small. *Musicking: The Meanings of Performing and Listening*. Wesleyan University Press, Middletown, Conneticut, 1998.

[19] A. Tanaka and A. Parkinson. Haptic wave: A cross-modal interface for visually impaired audio producers. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, pages 2150–2161. Aalborg University Copenhagen, 2016.

[20] UNESCO. Education and Disability: Analysis of Data from 49 Countriess. `http://uis.unesco.org/sites/default/files/documents/ip49-education-disability-2018-en.pdf`, 2017. Accessed: 25-04-2020.

[21] A. J. Withers. *Disability Politics & Theory*. Fernwood Publishing, Halifax & Winnipeg, 2012.

[21] `https://www.drakemusic.org/technology/instruments-projects/the-kellycaster/`

[22] `https://www.drakemusic.org/technology/dmlab-community/`