2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
ASEE
Paper ID #36809

Looking into the Design of Accessible Musical Instruments for Musicians with Physical Disabilities

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Introduction and Literature Review

With a longstanding history of usage for human creativity and expression as well as an opportunity for professional career development, music performance has been and must remain accessible to all those who desire to learn, perform, or enjoy it. Though the nature of music performance varies drastically today due to the availability of electronic instruments and audio technology in music venues, it is vital that accessibility and equity is ensured for performers of all sectors; from classical performers, to pop artists, to digital music performers and beyond. As outlined in Article 27 of the United Nations' Declaration of Human Rights [1], "Everyone has the right to freely participate in the cultural life of the community, to enjoy the arts and to share in scientific advancements and its benefits". Furthermore, Article 19 of this document states that "Everyone has the right to freedom of opinion and expression (.. .)". An increase in global awareness of diversity inclusion has led the United Nations among other leading humanity-driven organizations to emphasize a need for unrestricted access to the arts, and the removal of "barriers of entry" into certain workforces due to factors including but not limited to physical ability, race, gender, sexual orientation, or religion. Recognition of and removal of such barriers will ensure that all individuals may freely enjoy life, work, and expression of creativity. To create an equitable and just society, all musicians deserve to be offered opportunities to create music, and above all, to have access to music education that addresses all their needs and provides an effective and appropriate learning experience for them. Despite this, music-making is unfortunately not easily accessible for everyone. In its 2017-2018 data report of equality and diversity in creativity, Arts Council England [6] determined that only 3% of managers and 3% of directors at nationally recognized art organizations identify as disabled. In professional music organizations, the report states the London Symphony Orchestra, which remains England's most prestigious and successful orchestral group, only 1% of its staff identifies as disabled. Other major music performance organizations, including the Bristol Music Trust, North Music Trust, Philharmonia Orchestra, and Royal Liverpool Philharmonic Society, were all reported to have a disabled staff population of an estimated 2-3%. [6].

An overwhelming lack of accessibility and disabled representation in music has long created challenges for those individuals with physical disabilities looking to learn or perform music at a professional level - with much of this inequity coming from a lack of accessible instruments themselves. As stated by developers of the Strumni, a hybrid accessible guitar, engineers of accessible instruments hope to support "... a community for whom access barriers to music-making exist, and for whom design could play a part in lowering and removing those barriers. These barriers are subtle, however. It is not simply a case of measuring and assessing individuals' functional limitations and designing a system to alleviate them. Often the barrier to access is a social, rather than a technical one, and the solution might simply be a change in

environment. In our case, we were interested in the effects of the cultural associations that come with an instrument." [7]. Thus, the development of an accessibly-engineered instrument provides more than the ability to play music that it may supply to a user, but the cultural support and encouragement of disabled representation in music performance that these devices may cultivate, to see an eventual increase in the involvement of disabled musicians in professional music spaces. Due to the growing audience of individuals with disabilities, demand for accessible music is increasing, yet the current market of accessibly-engineered instruments is often too under researched and underdeveloped to support this demand. Thus, the music industry has become a necessary and promising endeavor for engineers and designers.

Recent efforts by software designers and instrument developers have created new opportunities in accessible music, through invention of entirely new instruments, adapted instruments, or musical accessories. In a survey of hands-free music devices conducted by Davanzo and Avanzini, it was found that "... the majority of the available channels is under-explored or completely unexplored. Many of these have potential for musical interactions, therefore future works should aim at exploiting them. Similarly, there is space for exploring different mappings strategies and more complex mapping cardinalities." [8]. Though prior research has proven the presence of design and study of accessible music instruments, further study must be done to determine how prototypes and past concepts have been effectively used by physically disabled musicians, whether intended for that audience or otherwise proven useful to that audience. It is vital that we analyze both availability and functionality of existing adapted instruments to clarify the needs of physically disabled music performers and prioritize broader equity in music.

In engineering education, this area of study is severely underrepresented, meaning many engineers may not even consider the industry as a potential area of involvement. The findings of this study may not only demonstrate how rare and inaccessible these instruments currently are due to a lack of widespread attention and development, but also outline what the major areas of concern are when designing these instruments. As it is an interdisciplinary subject, combining design and product development with music and equity in a professional field, inclusion of adapted instruments in the breadth of engineering education curriculums and research can not only improve the experience of physically disabled musicians, but also enable engineering students to develop a broader understanding of how engineering can be used to close gaps in equity.

Definitions and Terminology

The definitions provided below in Table 1 are used to refer instruments in groups based on their general purpose and functionality. Usage of such definitions allows distinction between the way in which engineers created the device, and what outside resources may be needed for the instrument to function, such as a computer to run a software or a speaker system. Additionally,

definitions are used to clarify whether the engineer of a certain instrument had the intention for their device to be used by physically disabled musicians, versus those which have been used as such without the engineer's specific intent.

Table 1. Definitions

Accessible Instruments	Overarching term used to describe instruments which are designed specifically to accommodate the access needs of disabled musicians.
Physical Instruments	Instruments which are strictly acoustic or controlled with simple electronics and do not require digital software to produce sound.
Hybrid Instruments	Instruments which require a physical device in addition to a digital software to be operated.
Digital Instruments	Instruments which are solely composed of software or electronic controllers and do not require a physical device.

Methods

To conduct a comprehensive review of the accessible musical instruments, we followed the method outlined by Yu and Roque (2019) [3], and Ehsan and Beebe (2018) [4]. The review method, called a survey analysis, required us to conduct multiple extensive internet searches, focusing especially on recommendations by organizations for physically disabled musicians and academic articles detailing the usefulness of new music technology towards this audience (i.e. "OHMI Trust" and "Drake Music"). We reviewed websites of currently developing technology as well as commercially available products, provided that a background of the product's functionality was available. Upon researching qualifying instruments, all were required to have some publicly accessible information detailing its usefulness to a physically disabled musician, which may be explained by the instrument designers themselves or by an outside party such as a testimony from a physically disabled musician to confirm the product's success in aiding them to perform or learn music, even if the device's original designer had not considered this as a primary feature of the instrument during the design process. The result of our search gave us 20 instruments. We then utilized content analysis [5], to review the instruments themselves and the common features are in them all. Patterns in the data were found via comparison of various instruments and commonalities within certain categories (Table 2 and 3).

Findings

After surveying and evaluating all the total of 20 instruments, we organized the instruments into two major categories as “Devices Designed With Specified Intention for Use by Musicians with Disabilities" with 13 instruments and “Devices Designed Without Specified Intention for Use by Musicians with Disabilities" with 7 instruments. Each instrument was then further organized into categories of physical, hybrid, or digital instruments. All were then closely examined, with recorded data including but not limited to the product’s name, its commercial availability, its functionality, and how much prior musical experience a user may be expected to have before using the instrument. To develop our findings on the impacts of each design category, we determined percentages of instruments which fit certain criteria to determine trends within the design of currently available and successful accessible instruments. Our primary goal was to determine what were the most common elements of a successful accessible instrument, as well as examine the current commercial availability and accessibility of these instruments.

We first examined the impact of intention of the designer; whether the creator intended for their device to be used by physically disabled musicians, or whether this intention was not explicitly stated / a primary focus of the instrument’s design. In our review, we found that of all surveyed instruments proven to be useful to physically disabled users, 65% were designed with the specific intention of use by disabled musicians, implying that in order to create an instrument which is accessible to a wide range of physical ability, the physically disabled demographic should be considered during the design process of a new instrument.

In examining commercial availability and price of accessible instruments, we determined that 60% of instruments were commercially available at the time of research, 35% of which were instruments not designed specifically for disabled users. However, only 25% of all instruments were available for less than $200 USD.

In examining functionality of these devices and adaptability of an accessible instrument to a wide range of physically disabled users, we found that 3 of all 20 instruments were designed with the intention to be controlled in multiple different ways - i.e compatible with both breath control and hand movement. Most instruments targeted a single method of user input.

In examining the design and aesthetic inspiration for these instruments, it was determined that of all 7 instruments not designed specifically for disabled users, 6 were classified as “new instruments”, meaning they did not intentionally imitate the design or structure of an existing instrument and were designed with consideration as an alternative to traditional musical instruments. Meanwhile, of all 13 instruments designed specifically for disabled users, 7 were intended to mimic traditional musical instruments, in both design and sound production, typically labeled as “adapted versions” of an existing musical instrument.

In examining the intended audience of an accessible musical instrument, we studied both the intended age of a user as well as their expected level of musical experience. In total, 8 of all 20 instruments were either intended for children or intended for all ages, with 6 of these being instruments designed specifically for users with disabilities. All of these 8 devices required little initial musical knowledge, and 7 out of the 12 devices created with specified intent were intended for adults with prior musical experience, due to their tendency to replace or modify an already existing instrument.

Table 2: Devices Designed With Specified Intention for Use by Musicians with Disabilities

	Product Name	Technology	Functionality	Parts	Adaptability / Size	Range of Musical Complexity	Intended Level of User's Musical Knowledge / Age	Aesthetic of Design	Price and Availability
Physical Instruments	Enabling Devices Adapted Instruments [11].	Mechanical or battery powered and controlled by various compatible switches sold separately.	Switch capabilities available include squeezing, head motion, blinking, "sip and puff", which trigger an instrument to sound.	Simplistic buttons, keys, etc. Generally composed of a basic music-making device and a switch.	Interchangeable switches allow the user to build their own instrument customized to their needs. Varies by instrument.	Usually produces a fixed sound or song played through speakers, or device sounds acoustically with limited variation.	Aimed towards beginners and students of music, used primarily to improve communication skills. Primarily children.	Bright colors and simplistic design intended to appeal to children and resemble other toys.	Varies by instrument, between $100 and $500. Available for purchase.
	Special Needs Toys Musical Instruments [12].	Mechanical/acoustic, some battery operated.	Controlled through simple body motion such as taps or pressing buttons.	Simplistic buttons, keys, etc. Generally composed of a basic music-making device and occasional drumstick or mallet.	Most devices are not adjustable, with pre-determined controls. Varies by instrument.	Usually produces a fixed sound or song played through speakers, or device sounds acoustically with limited variation.	Aimed towards beginners and students of music, used primarily to improve communication skills. Primarily children.	Bright colors and simplistic design intended to appeal to children and resemble other toys.	Varies by instrument, most less than $100 but select few are roughly $1000. Available for purchase.
	One-Handed Clarinets [13].	Fully acoustic	Controlled through pressing of keys to produce specific notes. Sound produced by the user's breath on clarinet reed.	Instrument, hanging stand attachable to neck, reeds, and stand.	Available in right-hand or left-hand versions. Handheld, same size as typical clarinet.	All notes and tones of a clarinet are available and other music techniques can be controlled by the user's breath control.	Intended for users familiar with playing a typical clarinet or with access to music education classes. Primarily adults.	Styled after traditional clarinet and similar in structure; adapted to be playable with only one hand instead of two.	£6000.00; available for purchase but handcrafted by designer and made to order.

	Adaptive Acoustic Guitar [14].	Acoustic, with a small electrically powered system enabling ease of playing chords.	Users push buttons along the neck of the guitar rather than forming chords on the frets of the guitar.	Guitar, electrically powered control system	Brightly colored buttons replace the need for complex chord hand positions. Same size as a typical acoustic guitar.	Similar range of musical complexity to a guitar, with some limited chord availability but full strumming techniques possible.	Intended for both beginners and seasoned guitar players. Available for all ages, primarily adults.	Resembles a typical acoustic guitar, brightly colored buttons indicate different chords and lay along the neck.	$1499.99 CAD. Available in other types of guitars. Shipping approximately 4 weeks with limited supply.
Hybrid Instruments	Jamboxx [15].	Powered via USB, plays notes through MIDI software.	Controlled through breath, by sipping or blowing on the mouthpiece.	Mouthpiece, frets (pro version only), USB and audio ports, attachable stand.	Can be held with one or two hands or with an attachable stand; adjustable to the user's lung capacity. Handheld, similar in size to a harmonica.	Changeable by instrument, pitch, key, volume, and rhythm through the software.	Two versions available, one suitable for beginners and one suitable for more experienced performers. All ages.	Modeled after a harmonica, playable as any instrument/genre.	Music Therapy Version: $279. Pro version: $399. Currently delayed production.
	Kellycaster [16].	Electrically powered and connected to a keyboard and device running MIDI software. A signal is collected from the strings and run through a Bela board.	A user strums the guitar strings and selects a chord or note on a keyboard. Sound is produced and altered through the software.	Guitar, keyboard, and digital software.	Designed with a short neck to allow easier strumming of guitar string, while the user's other hand selects chords on a keyboard. Slightly smaller and shorter than a typical guitar.	Same range of notes and tones as a typical electric guitar, other features adaptable through the supplemental software.	Intended for users familiar with music and guitar performance. Adults.	Originally modeled after Fender Telecaster, intended to resemble a traditional guitar.	Not currently for sale; ongoing development
	AirHarp [17].	An electrically powered	Controlled with a sweeping	AirHarp, compatible	Bright colored for users with	Most adaptations to music	Primarily beginners in music	Created in plywood	Not currently for sale

	sensor responds to user input and relays it to a digital music software.	hand motion, which triggers a sensor and interacts with the attached software.	software and computer.	limited vision and any note can be performed by pre-set motions of the body. Attached to a wheelchair for ease of use.	produced can be done through the attached software.	performance. Designed specifically for a sole user, who is an adult.	with brightly colored buttons for maximum visibility.	
Adapted Bass Guitar [10].	Bass guitar which allows fretting to be controlled by an external MIDI-powered controller.	A user strummings or picks the guitar's typical strings while attaching a controller which selects the note robotically.	Adapted bass guitar with mechanical fretting device, MIDI controller, computer or Bela board.	A variety of separately sold MIDI controllers allow users to play the bass with hand and select a note separately with a controller of their choice. Slightly smaller and shorter than bass guitar.	Similar to typical bass guitar, the user is able to play a full range of musical technique with the single-handed strumming.	Ideal for professional level players already familiar with music or bass guitar performance. Typically adults.	Styled in wood to model a typical bass guitar.	Not currently for sale
KeyWI [18].	The KeyWI works via a breath pressure sensor and MIDI keyboard, connectable to a software system through a Bela board.	Users breathe into a mouthpiece, triggering a sound and controlling its volume. Pitch is controlled using the attached keyboard.	Keyboard, mouthpiece, compatible device and audio software.	Breath control allows for a more intricate system of controls with limited physical input, and sensitivity of response to input can be altered to the user's needs. Playable with two hands, similar in size to a melodica.	Varied breath input allows for change in dynamics, with a wide range of pitches playable. Specific sound features may be changed through audio software.	Desirable for those who may not be familiar with specialized woodwind instruments and fingering. Typically adults.	Aims to be an "electronic wind instrument" - modeled after a melodica.	Remains in early phases of development; not currently for sale.
OrchLab	An ordinary	Pitch is	Touch	Can be played	Pitches and	Specialized to	Uses a	In early

	Touch Trombone [19].	trombone is fitted with a long touch sensor along its slide; sound is synthesized with a microcontroller	changed as the slide is moved (as with a regular trombone) and any touch on the device's slide produces a digital input, translated to sound	Trombone fitted with long sensor and microcontroller	using touch control only; mimics traditional brass instrument experience but does not need to be held or blown into. Same size as a typical trombone.	rhythm can be changed via simplistic controls, but further customization requires further programming; sound can be played through speakers sound separately	those who have no prior experience with brass instruments. All ages.	traditional trombone, aimed to be as authentic-looking as possible	prototyping phases, not available for commercial purchase
	Wheelchair One-Man Band [20].	Solar-powered keyboard is affixed to a user's wheelchair in order for them to perform music whilst being able to move.	Keyboard is solar-powered so that no external power source, batteries, or wires are required.	Keyboard, wheelchair attachments, internal speakers.	Pitches are played by pressing keys on the keyboard. Smaller than average keyboard, attachable to a wheelchair so that it fits in the user's lap.	Different sounds and pitches may be created depending on the keyboard which is used. Volume and instrument voice are widely adjustable.	Aimed towards users with familiarity of piano in order to be able to play the desired pitch on the keyboard. Primarily adults.	Designed primarily for ease of mobility while creating music; "on-the-go" design.	Not currently for sale.
Digital Instruments	EyeHarp [21].	EyeHarp software must run on a compatible device running Windows. Supplemental Tobii eye tracker software tracks eye movements to control the software.	A user looks at a specific tone or option on the screen to place their cursor there and produce a digital sound.	EyeHarp software, Tobii Eyetracker software (sold separately), compatible computer system (sold separately).	The software is customizable to the user and if desired, the software can be controlled using a mouse instead of an eye tracker. Size N/A.	Within the software, features such as instrument, chord, key, volume, and other features are changeable as desired.	Can be adapted to be used by beginners to music or professional performers. All ages.	Simplistic and easy to use software which contains large icons for each note in various colors.	Free limited version available; full version is £589.

	Clarion [22].	Software must run on a compatible device running Windows.	By hovering the cursor over an on-screen keyboard key, the desired note is produced through the software.	Clarion software, compatible controllers such as mouse/MIDI breath controller/eye tracker.	Compatible with some MIDI breath controllers and eye trackers. Size N/A.	Dynamics and expressions are controllable with specific mouse movements.	Targeted towards both beginners to music and for use in performance. Primarily children.	Based upon a conventional keyboard layout. Limited color with interactive graphics that react to input.	N/A, currently only available for users to test through organizations.

Table 3: Devices Designed Without Specified Intention for Use by Musicians with Disabilities

	Product Name	Technology	Functionality	Parts	Adaptability / Size	Range of Musical Complexity	Intended Level of User's Musical Knowledge / Age	Aesthetic of Design	Price and Availability
Physical Instruments	pBone Trumpet [23].	Fully acoustic; made with plastic and other light material which make the trumpets easier to hold and play than typical brass instruments.	The instrument is controlled by a user's breath input into a mouthpiece.	Instrument and plastic mouthpiece	Different materials available to allow users to hold an instrument more comfortably. Custom made mouthpieces allow ease of breath control. Handheld, similar in size to traditional brass instruments.	Produces all sounds and musical features of a typical brass instrument.	Intended for beginners to music, or those who may seek an alternative to begin learning brass instruments. All ages.	Designed to resemble traditional brass instruments, primarily trumpets and trombones. Some in bright colors.	Available for commercial purchase, price varies by instrument from $39.95 to $630.00.
Hybrid Instruments	MiMU Gloves [24].	Sensors within the glove record specific hand motions and communicate with the software via WiFi to	Through various movements of the hands and fingers, users are able to perform music kinetically.	One or two MiMU gloves, additional software and a compati	Can be programmable such that the user can determine which movements control which movements. Haptic feedback helps the user communicate. Fingerless gloves which fit most hands.	Although difficult to master, the gloves allow for a full range of musical expression through software.	Intended for users familiar with music and professional performance. Primarily adults.	Sleek design in all-black material, designed to look like fashionable sleeveless gloves.	Currently sold out due to chip shortage; sold as a pair for £2,599 and single for £1,299.

		produce sound.		ble compute r.					
	Orba [25].	A device which can create a wide range of musical tones and orchestral composition through simple button controls and an optional app.	Users control the device through its buttons, tilting the device, shaking it, and many other functions.	Orba 1/2 device, optional phone app to record a new instrume nt sound.	Many unique movements of the device can be used to control the device and can be played with one hand. Small, fits in the palm of a hand.	Various instrument sounds are available as well as various techniques such as tempo/key adjustment and looping tracks.	Intended for all levels of musical knowledge. Primarily adults.	All black with white markings indicating button controls, sleek and compact.	Orba (less customizable older version) $99.99. Orba 2 $149.99.
	Linnstrument [26].	Linnstrument is a MIDI controller controlled through precise finger movements	Subtle finger movements can be detected to reflect unique music controls	Linnstru ment MIDI controlle r, any MIDI synth or compute r running software sold separatel y	Can be played using a single finger. Also can be played atop a table, using a guitar strap; can be used with software, but functions without it. 5 pound 1 inch thin, similar in size to a small xylophone.	Wide range of precise and unique music complexity with arpeggiators and programmable keys	Intended for those familiar with music and willing to spend time learning the control system	Resembles a digital tablet, with brightly colored lights indicating notes being played	Linnstrument 128 (less customizable) $1099. Linnstrument original $1499
	Roli Seaboard RISE 2 [27].	Measured inputs of pressure and movement from a user's finger trigger notes and altered sounds	By changing applied pressure, side to side movement, and gliding motions, users can input	Seaboar d device and included Equator2 software	Can be played with specified finger movements; small frets under the silicone top allow for more accurate precision. Desktop-sized, similar in size to a typing	Over 1400 different instrument sounds available in the software are compatible with the	Intended for those familiar with music and willing to spend time learning the control system. Primarily adults.	Sleek design, all-black device which mimics the layout of a musical keyboard but has very few	Pre-order available; $1,399

		through the attached software.	specific notes or sounds like vibrato by touching the raised bumps on the surface.		keyboard.	device, along with advanced music and sound controls		visible buttons or controls	
	Moog Theremini [28].	Contact-free device which is controlled by simple hand movements next to a sensor, triggering a note which can be played through a speaker or music software	The user holds their hands above the music and controls the sound through various hand motions.	Theremin synthesizer, optional sound system or software for more control	Built-in tuner displays the pitch being played to aid the user; a corrective pitch mode allows for only exact pitches to be played. Desktop-size, with a larger sensor pointing upwards.	32 editable presets allow the user to adapt the sound, scale, delay, and more to be altered	Intende for both educational use by musicians new to performance as well as seasoned performers seeking a new instrument experience	Retro-style synthesizer with knobs for system controls and a digital screen to display pitch	Sold by authorized sellers for $399
Digital Instruments	EXA: The Infinite Instrument [29].	EXA Software is compatible with most VR systems and simulates playing an instrument entirely virtually	A user wearing a VR headset and holding VR controllers can interact with the immersive space and play music	EXA software, compatible VR headset and computer system (sold separately)	Can be used with most VR headsets. Size N/A.	Musical features such as instrument, layout of notes, and key can be controlled through the software	Available to users at any level of musical experience, including those looking to record professional music. All ages.	Simplistic and easy to use software which contains large icons for each note in various colors	Software commercially sold for $14.99.

Discussion of Results

Engineering education has a lack of representation in this area of study, meaning many engineers may not even consider the industry as a potential area of involvement. The findings of this study may not only demonstrate how limited and inaccessible these instruments currently are due to a lack of widespread attention and development, but also outline what the major areas of concern are when designing these instruments. Inclusion of adapted instruments in the breadth of engineering education curriculums and research can not only improve the experience of physically disabled musicians but also enable engineering students to develop a broader understanding of how engineering can be used to close gaps in equity.

Upon reviewing the survey of adaptive instruments, we were able to identify 9 major categories of design characteristics that appear to most contribute to an adapted instrument's usefulness to a physically disabled musician. These categories were analyzed per instrument as seen in Tables 2 and 3. By analyzing trends within these tables (i.e. determining most common expected age of user for all hybrid instruments), the summary of these trends can be found in the previous section. Overall, the devices vary in their intended users, musical complexity, adaptability, and price. Some are intended for actually disabled people, and some are not. Some are designed for beginners, while others are intended for more experienced musicians. Some are designed to be more accessible for people with disabilities, while others are intended for use in professional settings. The prices also vary widely, with some devices being relatively affordable and others being quite expensive.

Additionally, the findings reported here illustrate common characteristics that contribute to the effectiveness, accessibility, creativity, and availability of each category of instrument. Implications of combining ideal characteristics in designing future adapted instruments may result in more effective devices, and greater inclusivity in professional music. We also examined the availability of these devices and detailed the current experience of physically disabled musicians, based on the breadth of adapted instruments available. We further provide insights for engineers and designers, the musical community and industry, and engineering educators to enable greater understanding of the importance and positive social implications of accessible instruments.

Experience Of Disabled Community

While more suitable for those with physical disabilities and generally compatible with a wide variety of specific users' needs, instruments intended for users of physical disabilities are often priced highly and not sold commercially due to long and costly prototyping phases. This limits accessibility and restricts equity in professional music performance. Such devices in physical and hybrid forms additionally tend to resemble traditional instruments. The likely reason for this is aiding its users in feeling less alienated from musicians who perform with traditional instruments. It replicates and provides the traditional music-making experience for those who

normally would be physically unable to do so due to limitations of traditional instruments. Input from disabled musicians is vital to understanding the needs of this audience, and is why the direct collaboration of engineers and physically disabled musicians has produced the most positive user testimony. As stated by Baker, “It is important to remember that two students who have the same disability may not benefit from the same adaptations and modifications. Every student is different, yet each needs to be taught in ways that allow them to learn most..” [9]. Thus, there is a need to amplify the unique voices of those with any variety of physical disability, and broaden this field such that more individuals may be supported by it.

Insights for Engineers and Designers

Physical instruments intended for users with disabilities are rare, particularly concerning solely physical instruments, as the consideration of one’s range of motion and mobility must be accounted for in order for the instrument to be played by a user with a physical disability. Because of its limited market, instruments both intentionally designed for and used by physically disabled musicians are often in limited production and distribution. In this case, solely digital devices like music production software provide a viable option for large-scale new non-traditional instruments because there is no need for development, prototyping, and production of a physical product. Many tools compatible with software such as MIDI breath controllers or VR sets are already largely available, more so than the tools needed for physical or hybrid instruments. However, the lack of a physical instrument may detract from the typical musical experience. Despite the successes and versatility of many instruments designed for users with disabilities, it is rare that one device is able to address the needs of multiple differing users. For example, a device may be well suited towards a one-handed user, but not a user with limited range of motion in their fingers. The goal of many accessible instruments is to address a specific issue and audience, in order to create instrument options for as wide an audience as possible while maintaining authenticity and musical complexity of the device. It was additionally noted that certain demographics are under-addressed, for example few devices address the needs of blind or hearing-impaired users. These findings align with those of Frid, who states, “In terms of target user groups, one can conclude that little attention has been paid to older adults or really young children in this context. Also, relatively little has been done for persons with visual or hearing impairment.” [2]. A possible explanation for these areas of less focus may be that few solutions have yet been explored for these demographics, requiring further research and work alongside users who fall within these demographics to determine what characteristics of an accessible instrument may best support them.

Insights for Musical Community and Industry

Physical instruments designed intentionally for users with disabilities are typically intended for children and those unfamiliar to music. Brightly colored, simplistic designs with easy-to-use controls make these an ideal tool for accessible music education, but not necessarily professional performance. They often provide an appropriate entrance into the field of music and encourage

and inspire young musicians. The instruments not designed intentionally for users with disabilities have been included in this survey due to their success when used by physically disabled musicians looking for alternatives to traditional music. These tools, particularly those in hybrid or software design, are generally unique, and do not necessarily replicate an existing instrument or explore musicality in new forms to push the bounds of traditional music performance. Growth of digital instruments for use in musical performance in general has created new opportunities for disabled musicians, due to their tendency to be more easily played and used than traditional acoustic instruments. Additionally, it eliminates a feeling of alienation a user may feel due to being unable to perform with a traditional instrument, because they encourage the furtherment of digital music devices for musicians of all ability and knowledge to explore more modern music-making tools which can provide all new techniques and sounds.

Insights for Engineering Educators

In order for more engineers and designers to become aware of their needed contribution to this topic, it is vital that engineering educators become familiar with the aspects of this technology that are most effective and most important to the audience of physically disabled musicians, as this will allow further education on the topic and encourage engineering students to consider involvement in the music industry with a focus on promoting equity. In particular, our study found that 3 of all 20 instruments were designed with the intention to be controlled in multiple different ways. However, having these various methods of input makes a single instrument highly more useful to a wider range of users - yet these multi-input devices are largely unexplored [8]. Many of the organizations studied within this survey, such as OHMI Trust and Drake Music, frequently work alongside engineering educators and students to develop their prototypes and encourage collaboration between engineers and disabled musicians to create effective, accessible music technology. While this provides great opportunities to support individual musicians, it does not address problems we found within broad accessibility - for example, 60% of those devices specifically intended for physically disabled users were not commercially available for purchase. Engineering education serves as a pathway to broaden the focus on adapted instruments, as it allows for future engineers to be well-informed on the limitations of current devices and, if included in engineering curriculums, can encourage development of instruments that are both effective and commercially available due to an engineering student's knowledge of product markets and potential to partner with a larger corporation for production. Greater focus on this collaboration within engineering education departments can not only allow students to explore more interdisciplinary and practical applications of their studies, but also greater support the community of disabled musicians and increase the resources of these organizations so that more devices may become commercially available, affordable, and effective to the larger community of disabled musicians.

What's Next?

The development of accessibly-engineered instruments provides more than the ability to play music that it may supply to a user, but the cultural support and encouragement of disabled representation in music performance that these devices may cultivate, to see an eventual increase in the involvement of disabled musicians in professional music spaces. Due to the growing audience of individuals with disabilities, demand for accessible music is increasing, yet the current market of accessibly-engineered instruments is often too under researched and underdeveloped to support this demand. Thus, the music industry has become a necessary and promising endeavor for engineers and designers.

Future research into this topic may require a survey of physically disabled musicians and performers to determine what characteristics they feel best accommodate their needs and what design features appeal to them best. User testimony should be paramount in any future development of adapted instruments, as it proves to be most successful in creating adapted instruments which are successful in testing with disabled users. Additionally, addressing limitations of current instruments and combining all ideal features of a musical instrument can be used to conduct research and development for a new instrument which can be utilized by physically disabled users.

References

1. United Nations. “Universal Declaration of Human Rights.” *United Nations*, United Nations, 10 Dec. 1948, www.un.org/en/about-us/universal-declaration-of-human-rights.
2. Frid, Emma. “Accessible Digital Musical Instruments—a Review of Musical Interfaces in Inclusive Music Practice.” *ResearchGate*, July 2019, www.researchgate.net/publication/334715529_Accessible_Digital_Musical_Instruments-A_Review_of_Musical_Interfaces_in_Inclusive_Music_Practice. Accessed 27 Feb. 2023.
3. Yu, J., & Roque, R. (2019). A review of computational toys and kits for young children. *International Journal of Child-Computer Interaction*, *21*, 17-36.
4. Ehsan, et al. M. E. (2017, June). Promoting computational thinking in children using apps. In *2017 ASEE Annual Conference & Exposition*.
5. Kondracki, N. L., et al. (2002). Content analysis: Review of methods and their applications in nutrition education. *Journal of nutrition education and behavior*, *34*(4), 224-230.
6. England, A. C. (2018). Equality, diversity and the creative case. *A data report*, *16*.
7. Harrison, Jacob, et al. *Accessible Instruments in the Wild: Engaging with a Community of* ... May 2019, http://library.usc.edu.ph/ACM/CHI2019/2exabs/LBW0247.pdf.
8. N. Davanzo and F. Avanzini, "Hands-Free Accessible Digital Musical Instruments: Conceptual Framework, Challenges, and Perspectives," in IEEE Access, vol. 8, pp. 163975-163995, 2020, doi: 10.1109/ACCESS.2020.3019978.

9. Baker, Eric. (2018). *The Inclusive Orchestra: Adapting String Instruments and Instruction for Musicians with Special Needs* . https://dsc.duq.edu/cgi/viewcontent.cgi?article=1023&context=urss.
10. Harrison, Jacob. “An Adapted Bass Guitar for One-Handed Playing.” *ResearchGate*, https://www.researchgate.net/publication/325651424_An_Adapted_Bass_Guitar_for_One-Handed_Playing.
11. “Adapted Musical Instruments for Sale Archives.” *Enabling Devices*, enablingdevices.com/product-category/adapted-toys-games/adapted-musical-instruments/. Accessed 30 Apr. 2023.
12. “Special Needs Musical Instruments | TFH Special Needs Toys USA.” *Specialneedstoys.com*, specialneedstoys.com/usa/auditory/musical-instruments.
13. Worrell, Peter. “Welcome to the One Handed Clarinet.” *Www.peterworrell.co.uk*, www.peterworrell.co.uk/onehandedclarinet.htm.
14. “Adaptive Acoustic Guitar.” *Inclusiveinstruments*, inclusiveinstruments.org/products/traditional.
15. “Jamboxx - Hands Free, Breath-Powered Instrument - Music for All.” *Jamboxx*, www.jamboxx.com/.
16. *The Kellycaster | Drake Music*. www.drakemusic.org/technology/instruments-projects/the-kellycaster/.
17. “AirHarp.” *Ccrma.stanford.edu*, ccrma.stanford.edu/~adam/airharp/. Accessed 30 Apr. 2023.
18. Caren, Matthew. “KeyWI: An Expressive and Accessible Electronic Wind Instrument.” *Keywi.org*, keywi.org/. Accessed 30 Apr. 2023.
19. *OrchLab Instruments – Touch Trombone & Oboe | Drake Music*. www.drakemusic.org/technology/instruments-projects/orchlab-instruments-touch-trombone-oboe/. Accessed 30 Apr. 2023.
20. *Wheelchair One-Man-Band | Drake Music*. www.drakemusic.org/technology/instruments-projects/wheelchair-one-man-band/. Accessed 30 Apr. 2023.
21. “EyeHarp - Playing Music with the Eyes.” *EyeHarp*, eyeharp.org/.
22. “Clarion.” *Open up Music*, www.openupmusic.org/clarion.
23. “PTrumpet |.” *Pbone.co.uk*, 5 Oct. 2019, pbone.co.uk/product/ptrumpet/. Accessed 30 Apr. 2023.
24. “MI·MU | Home.” *Mimugloves.com*, mimugloves.com/.
25. “Introducing Orba 2 by Artiphon.” *Artiphon*, artiphon.com/pages/orba. Accessed 30 Apr. 2023.
26. Linn, Roger. “Linnstrument.” *Www.rogerlinndesign.com*, www.rogerlinndesign.com/linnstrument.
27. “Seaboard RISE 2 | ROLI.” *Roli.com*, roli.com/products/seaboard/rise2.
28. “Theremini.” *Moog Music*,

www.moogmusic.com/products/etherwave-theremins/theremini.
29. Kinstner, Zach. "'EXA: The Infinite Instrument' User Guide." *Medium*, 8 Apr. 2017, medium.com/@zachkinstner/exa-the-infinite-instrument-user-guide-9b8ff6ab6bf7. Accessed 30 Apr. 2023.