Design Considerations for Instruments for Users with Complex Needs in SEN Settings

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ABSTRACT
Music technology can provide unique opportunities to allow access to music making for those with complex needs in special educational needs (SEN) settings. Whilst there is a growing trend of research in this area, technology has been shown to face a variety of issues leading to underuse in this context. This paper reviews issues raised in literature and in practice for the use of music technology in SEN settings. The paper then reviews existing principles and frameworks for designing digital musical instruments (DMIs.) The reviews of literature and current frameworks are then used to inform a set of design considerations for instruments for users with complex needs, and in SEN settings. 18 design considerations are presented with connections to literature and practice. An implementation example including future work is presented, and finally a conclusion is then offered.

Author Keywords
assistive technologies, adapted technology, music technology, novel interfaces, special education, action research, modular systems

ACM Classification

• Human-centered computing~HCI theory, concepts and models • Human-centered computing~Interface design prototyping • Applied computing~Sound and music computing • Hardware~Sound-based input / output • Hardware~Haptic devices

1. INTRODUCTION
Music technology can provide unique opportunities to access music making for those with complex needs. The term complex needs can refer to spectrum of cognitive, physical, sensory impairments and/or disabilities, or emotional and behavioral difficulties. There is a growing trend of research [1] and creation of tools ([2], [3]) showing that these technologies can be invaluable at facilitating interaction with sound for those who face barriers when accessing traditional musical instruments. Literature has shown there is not a strong uptake of music technology in the special educational needs (SEN) setting ([4], [5]) and several issues have been flagged as contributing to their lack of use. These include the financial cost of music technology, space needed to store and set up, and a fear, dislike or indifference to technology [6] leading to "a potential lack of confidence with putting technology into practice [7]". Musical output can also be seen as being uninspiring, artificial and lacking expression [8] and impersonal and lacking sophistication [7]. Technology can be seen as a barrier when coupled with a lack of formal training and exposure, [5] and the perceived need for insider knowledge when in use [7]. However, when technology is used successfully it can provide unparalleled access to musical expression for those with complex needs [1]. Creating technology for use within this setting can be difficult and this paper attempts to assist designers with issues specific to users with complex needs and the special educational needs (SEN) setting. 15 years ago, Perry Cook created his principles for designing computer music controllers [9] and these principles have provided a guiding light to many DMI designers since. The following paper was inspired by Cook's 2001 paper and introduces some novel principles of its own for the designing of instruments for users with complex needs and in SEN settings. The paper begins by laying down the context from which these principles have been derived, moves into the background from which the principles are formed, reviews literature pertinent to the design of digital musical instruments and then outlines 18 design principles, with links to literature and data gathered. An implementation example is offered and a conclusion featuring future considerations.

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2. CONTEXT
Many children and young people (CYP) within SEN schools might need additional help with "thinking and understanding, physical or sensory difficulties, emotional and behavioral difficulties, difficulties with speech and language, and also how to relate and behave with other people" [10]. Individuals with severe complex needs can experience "minimal movement, disordered movement, altered states on consciousness, and may have no verbal communication". [1] Engaging in musical expression can be beneficial to those with complex needs, providing an opportunity for expression to enhance wellbeing [11], and opportunities for communication helping to establish a sense of identity [12]. However, access to music making can be difficult in terms of physically being able to interact with the tools provided, and cognitively being able to understand and use traditional instruments or equipment designed for the typical user, and difficulties when playing together in an ensemble. Whilst there are many instruments aimed at typically able users, there are few specialist musical instruments available to assist users with complex needs. Larsen et al [13] offer a recent review of such custom technologies, the most notable being the Soundbeam developed in the late 80s [2] and more recently the Skoog [3]. Music technology that is developed is often underused with a compounding factor being that music based sessions are facilitated by non-musical and/or non-technical practitioners. Hahna et al [4] surveyed Music Therapists about their feelings towards technology and found distress, fear, lack of confidence, lack of interest, dislike, or belief that music technology is not appropriate in music therapy clinical work, or not appropriate for particular clientele were some of the reasons against technology usage. Some participants in the same survey stated that they thought that music technology was intrusive in sessions. Farrimond et al [6] also back these findings in their report. Technology is often seen as hard to set-up, hard to use, too expensive, hard to store, or not tailored well for the CYP using them thus equipment gets left to gather dust on the shelf or is only used by the designated "techie" person.

3. BACKGROUND

Elements of the design considerations presented here stem from previous undergraduate research work where the first author undertook a 9-month placement as a creative technologist alongside author Luke Woodbury. Woodbury is the embedded interactive designer of 7 years within the Three Ways School in Bath, a leading specialist school who are progressive about their usage of technology. This paper also features a continuation of this research as part of the engineering doctorate (EngD), with the overriding topic being music technology for users with complex needs. The research is in its 2nd year and is also a culmination of several years' experience within the field, accounts from several sources, and numerous exchanges between the authors, and a variety of other professionals within the SEN field. This research has originated from frustrations with current hardware and software systems used to allow CYP access to music within an SEN setting and as such is following an action research (AR) methodology. AR allows the research to be participatory, with those using the technology being at the centre of the research as co-researcher stakeholders. The aim of AR is to try and create new solutions that can be left within the context they are developed, and with co-researcher stakeholders taking ownership and autonomously carrying forward the created technology.

4. EXISTING FRAMEWORKS FOR DESIGN

Several existing frameworks and considerations for design have informed this paper. Hunt et al's [14] considerations for the improvement of technological solutions suggest three areas needing improvement to create enticing devices for users and those facilitating their use: "**audiovisual instrument design**"- creating instruments for users with minimal movement with the same variety and feedback as acoustic instruments. "**Technical infrastructure refinement**"- localising the sound via external amplification and having the ability to make new sound worlds comparable to conventional instruments by customising to the individual's needs. "**Clinical practice integration**" - having an open-ended flexible toolkit that is inspiring but not frightening to users.

Jorda [15] provides guidance in creating instruments with longevity that can draw users in, by looking at issues of balance (complexity vs simplicity), playability, learning curve and instrument efficiency, and how they come together to allow for a meaningful experience.

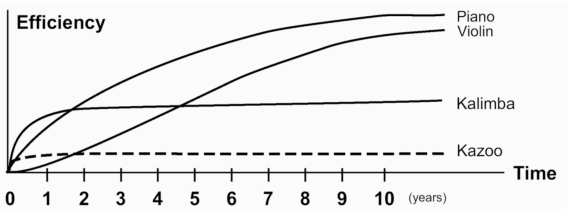

Figure 1 "Approximate learning curve for the kazoo, kalimba, piano, and violin over a period of 10 years" [15].

The seven heuristics as proposed by Wallis et el [16] describe the qualities of musical instruments that inspire long-term engagement; incrementality (learning curve to encourage flow), complexity (ceiling of expertise), immediacy (how accessible the instrument is), ownership (personal configurability to achieve own style), operational freedom (affordances offered by the interface to allow for interactive complexity), demonstrability (the ability to perform and share with others) and cooperation (the opportunity to play as ensemble). Each heuristic can be used to inform the design process of creating new instruments within the SEN setting.

There are also elements presented here that connect with Morreale et al's [17] MINUET framework for musical interface design grounded in the experience of the player. The framework is guided by looking at how people, activities, contexts and technologies combine, and uses a two-stage design process consisting of goals and specifications to help designers "position, shape, and evaluate their system" (p467).

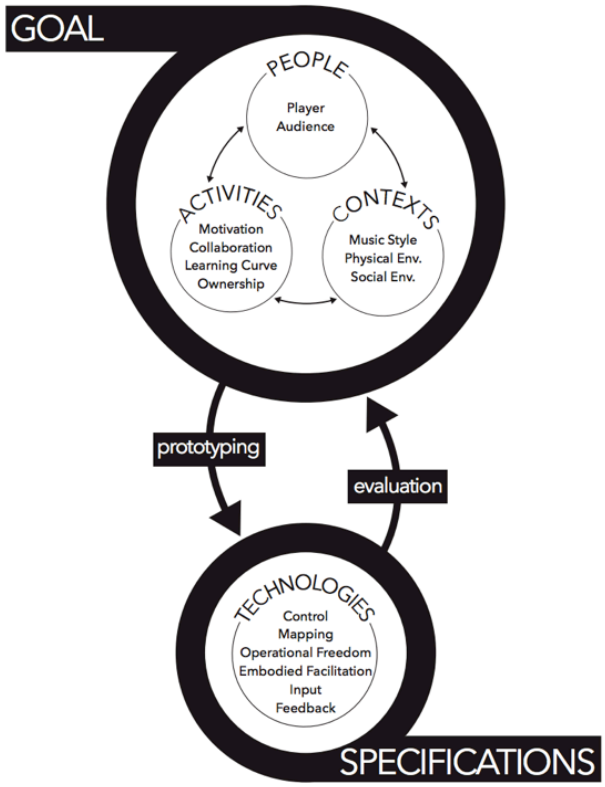

Figure 2 - MINUET framework [17]

5. DESIGN CONSIDERATIONS

Presented below are 18 design considerations for instruments for users with complex needs in SEN settings. Considerations developed from literature reviewed, practice based work by the authors directly and via reports of similar work, and continuing doctoral research by the first author. Much like Perry Cook's (2001) design principles some are human/artistic and some are technical, or in different terms some relate to the instrument, some to the user and others relate to the context of use. They begin with a focus on the design of the instrument itself, move out into the design of the system and then into designing for the context of use.

1. **Consider each layer of the system** – There is commonly a modular 3-part description to DMIs. Moog [18] identified "the sound generator, the interface between the musician and the sound generator, and the tactile and visual reality of the instrument that makes a musician feel good when using it" (p214), Pressing [19]; the control interface, the processor, and the output, and Hunt et al [20] the interface, abstract, and synthesis mapping layers. Thinking of the separate elements creates a modular system where each element can be enhanced, replaced [6], adapted, modified, or automated depending on the need of the musician. This enables a tailoring to an individual's specific needs and capabilities, both in terms of how they can interact with the system (sensor inputs, gestural capability, or other ways the individual can provide energy to the system), and

what the system provides back (feedback mechanism and also content of that mechanism). Making interactions meaningful with mapping between the player's control of the instrument and the sound produced being one of the most dominant issues in the creation of new musical interfaces [21] and each layer of a system allows for meaning to be added and also allows for the system to provide support where needed in a flexible way.

2. Decoupling the action and sound production – In DMIs the excitation-sonification relationship is broken. This can lead to opportunities but can also create problems. The dislocation of excitation and sonification is exciting [22], in that any small movement can be used to produce large sonic changes but can also cause problems with cause and effect for some users as dislocation of action and reaction can be an abstract concept for some. Feedback is often provided separately from where the excitation occurred and, if not delivered in a way that can be accessed by the user, can render gestures meaningless. According to the stakeholders at Three Ways school to mitigate this feedback should be placed close to creation of sound, either embedded or with an amplifier, for example, touching to the musician's seat for vibration [personal communication].

3. Expression vs Constraint – How much expression is offered can affect how engaging the instrument is depending on the user. "The one-for-one (mapping) scheme may be inspired by a wish on the part of the instrument designer to make the instrument 'easy to play', but it is a debatable point whether this simplicity is in fact a desirable thing, or whether this results in an instrument lacking in expressive capability" [23 p1023]. Mappings which are not one-to-one are more engaging for users [24] however "good musical instruments must strike the right balance between challenge, frustration and boredom" [15 p174]. Rich experiences tend not to come from devices that are too simple, however devices that are too complex can "alienate the user before their richness can be extracted" [25] so there needs to be a balance between both elements that suit the musician playing. Instruments such as the Skoog (a tactile 'squishy' controller based on physical modelling) offer virtuosic control for musicians with high functioning cognitive ability and low motor skill however may not be suited to an individual with low cognitive ability and low motor skill. In a SEN setting expression vs constraint are better expressed as scalability and configurability, used to provide a system that suits the individual's needs and is empowering vs overpowering. Scalability and configurability can be provided at the interface level by using flexible modular input mechanisms, by dynamic interfaces that can be configured to the user's abilities to create potentially complex and expressive musical gesture from simple inputs, and/or at the content level by being able to map these inputs to meaningful content. There is an important balance to strike here as teachers Kirsty Hafford and Ben Edwards say 'opening up expression means it takes longer to get outcomes and in an environment driven by outcomes things can get done for people which can lead to an unsatisfactory learning experience [personal communication]. Instruments should be able to scale in content to suit the user's ability and allow for improvement over time. Making things configurable and scalable to the individuals using them is paramount in this context as there is no typical user.

4. Continuum of control – Johnston et al [26] identify three modes of interaction characterising the musicians approach to virtual instruments. Each offer different levels of control over the system; Instrumental: where the musician prioritises detailed control, ornamental: where the musician surrenders detailed control to allow for the software to transform the sound, and conversational: a two-way conversation between the musician and the virtual instrument that shapes the musical direction the musician takes. In the SEN setting there needs to be more of a continuum of control. This continuum of computer control vs human control of the system can be used to scaffold the capabilities of the individual and provide support when needed whilst allow maximum control of the instrument. For example, consider playing a melody; a switch (which is a very common assistive technology tool) could be used to scroll through a melody note by note, or a movement in and out of an ultrasonic beam, such as those featured on the Soundbeam [2], could provide the same potential but the musician has to successfully select the right zone to break on the beam, both these musicians are being supported to different degrees to achieve the same outcome. Systems can support those with different levels of needs to play together.

5. Natural interaction (when I move you move) – This principle relates to matching the gesture of excitation to the sonification in a way that makes sense to the player. "a direct relationship is established between the physical gesture, the nature of the stimuli and the perceived outcome. The resulting awareness is multifaceted and has been at the core of musical performance for centuries" [22]. "The gesture used has to have an intuitive result from the sound; e.g. you can hit a snare drum in a multitude of ways and produce a variety of sounds and dynamics. The sound should genuinely express the nature of the movement in a 'symbiotic' relationship" [27] i.e. if you push harder the sound is louder; what a player might naturally expect from an interaction of that where the form and function link with the shape of the design style. Instruments that mimic a natural interaction to traditional instruments (for example using valve style buttons for recreating a trumpet valve) can offer an experience close to the traditional instrument, giving a sense of familiarity to the user as to what is expected from the interaction. Another important add-on is the ability to stop all the sound. Hewitt [27] suggests that "being able to make no sound without having to withdraw from the motion-sensing field – like stopping a bow on a cello string without lifting it up" is of high importance. Gesture to sonification should be tailored to the individual and their range of movement or capability allows mapping of an interaction that is natural to that individual.

6. Form should inspire interaction – Acoustic instruments are naturally pleasing to look at and feel. They are enjoyable artefacts with history to them and are formed from natural materials. Tactile materials with a shape, texture, feel, smell and feedback can draw users in and stimulate all the senses. Instruments designed with new materiality and form provide new opportunities to inspire interaction and allow configuration of the instrument to suit the individual's preference and need, both in terms of look and feel. Some CYP may be averse to touching certain textures and others may have favourite colours and textures that can be used to encourage engagement. One of the criticisms of the Skoog was that it was very child-like in appearance, something that has been rectified with the Skoog 2.0 [3].

7. Robust/Durable/Stable – "Construction can never be solid enough, especially when it is to be used by children" [28]. Designs should be as robust as possible to ensure they have the durability to cope with the context they will be used in. There is also a need for the instruments and any accompanying software to be as stable as possible. If there are malfunctions, then this can be discouraging for the users and those around them and may lead to technologies being abandoned.

8. Respect the feedback loop – Interaction between the person and the instrument typically takes place through the aural and visual feedback loop with the performer making decisions in real-time on that basis [19]. For users with complex needs these channels of feedback may be impaired, therefore feedback should be provided in a way that make sense to the user allowing access and resonance with the instrument. Within stakeholder meetings tactile/haptic and vibration feedback were identified as important to reinforce cause

and effect. Light and visuals were also found to provide structure and stimulate responses.

As well as the feedback from playing the instrument there should be adequate feedback for the navigation of the instruments configuration. To allow for navigation feedback should be visual, audible, and/or tactile allowing for scalability to physical, cognitive, and sensory ability [6].

9. Make it meaningful to those involved – This means creating technology that allows for the user to add their own content/samples and give input for how the instrument works in a customisable way, thus having some ownership over the instrument design, and not only making it work based on individual needs in terms of their cognitive/sensory/motor skills but also making it carry meaning for them in terms of content. One of the criticisms of some previous DMI's specifically aimed at the SEN market is that their sound palettes are impersonal and lacking in sophistication [7]. Mike Whitlock suggests this can be negated by leaving the sound palette open enabling users to add their own sounds that carry meaning for the individuals using them [personal communications].

10. If you can add a microphone- do it – Use of voice is very important in an SEN context. It can provide an avenue for exploring self-experience, communication and relational possibilities [29]. A microphone can provide access to allow for those that cannot interact with a system in any other way. Stakeholders from the Three Ways School say that voice and voice manipulation is a good avenue for engagement for some CYP that would otherwise be unable to physically interact with a system and also allows for addition of sampled sounds from the environment to be input into the system [personal communication].

11. Think of sound quality – Make the sound quality high. The overriding use of the MIDI protocol and the general MIDI sound range in the past has left a lot to be desired with the type of sounds offered and the inherent lack of expressive potential offered. The "lack of subtlety has meant that timbres can wear thin [20]". Hewitt [27] suggests that ideally there should be "an option to be polyphonic – played with multiple movements simultaneously". Whitlock also suggests this is useful for building up rich sonic soundscapes by layering triggered sounds [personal communication]. The quality of onboard sound and the quality and option for outboard sound is important as sound may be amplified through a PA system or via amps or monitors or headphones. The ability to adjust sound levels to suit the user is important as some CYP may be very sensitive to sound and others may have hearing impairments. Localising the sound by placing amps or monitors close to the player is common practice within the school setting to reinforce cause and effect.

12. Facilitate choice/ offer consistency – Instruments in the main are set up by the musician playing them, in the school context this is not the case. Rather, there is a tendency for those facilitating the musician or the session to choose the setup of the technology both in terms of how gestures are captured and the musical output of the system. When decisions are made for people, this leads to two problems; relinquished choice of both interaction style and output received, and potential for moving of the goalposts or in other words programmability is a curse [9]. Within the context of musicians with complex needs there can be a tendency of involuntarily relinquished choice meaning that things are often chosen for people instead of with them. Enabling users to select for themselves, if they can, the level and type of control they have should be paramount. Hunt et al speak of the dangers of configurable instruments in that the "goalposts are constantly being moved" [14 p364]. They say traditional instruments do not change character from one session to the next and musicians undergo a process of learning to configuring their instrument. Changing goalposts can mean that some users never have the chance to get to grips with their instrument, this can be particularly damaging if their needs mean that predictability is a strong motivator. There could also be the danger of learned helplessness with users not feeling like they have control over the system or feeling like it is their fault that the instrument is responding differently. Hunt et al suggest perhaps setting up an instrument with the same configuration for each particular situation [14]. This can be made more difficult if the particular situation changes often as can be the case in the school setting with different locations and staff being used to facilitate sessions on a pragmatic basis. A built-in system to recall configurations would help with this.

13. Participatory design – Teacher Kirsty Hafford says that creating with the user provides a more authentic picture, Woodbury adds that this is important to establish where the design should go and highlights issues that may not be obvious to the digital musical instrument designer [personal communication]. Only the users and those who work closely with them will best know their needs in terms of interacting with an instrument. Working in a participatory way can allow for rapidly working out kinks and problems with any designs. In our experience a designer cannot possibly guess at how a user with an alternative thought process will respond to a particular design which may have taken hours of work, so participatory design also means a reduction in wasted time.

14. Small, cheap and easy to use – Barry Farrimond describes the first instrument he designed for users with complex needs and how it was only revealed to be big, expensive, and hard to use upon its maiden voyage of use [30]. Typically, in a school there is limited space and budgets, both in terms of time spent by staff training to use the technology and money available to buy technology [4]. Having things that are off-the-shelf/affordable, easy to programme with minimal set-up needed, that can be made compact are paramount [27, 6]. Expense and need for insider knowledge lead to tools being abandoned [7]. Plug-and-play is the ideal in terms of allowing the system to work within the context as ease of use is currently a barrier to technology usage. Gallin and Sirguy [31] give 6 points that impacted on the design process of their plug-and-play system that can be useful to consider; "1) the technical side must be transparent to the user; 2) the design is focused on the way the interface will be used; 3) the accessible parameters are only "visible" setting parameters; 4) it imposes a wide compatibility with existing OS, softwares, MIDI devices and other hardware interfaces; 5) it requires different levels of use: ready-to-use; internal parameter access via the editor; and Max programming; 6) it requires compatibility with other communication protocols (p437)". These points cover several important areas that allow these systems to work in context and with other systems already in place whilst not overwhelming those facilitating the use of the system. Once the system is up and running technology can be adapted to the situation by adapting equipment as needed in practice, and allowing equipment to work alongside other equipment. The more familiarity that can be provided as part of the design the better as then users won't be so fearful of using the technology, for example allow switches that are already used in the school to be plugged into the designed modular instrument. This allows for components to be added as user's familiarity with the system grows. To enhance ease of use, remove unnecessary complexity like jargon, convolution, big manuals, and hard configuration should be avoided [6] and any terminology or language used should be familiar to the user. Designs should be easy to use physically (for example jack sockets and connectors can be hard to pull apart) in making sure the system is suitable for the amount of strength the user is capable of. Instruments should also be able to be mounted, with standard mounting fixtures and arms, to enable easy positioning.

15. Wires are not awesome – Instruments that are wireless enable easier sharing and cut down on health and safety issues, they also mean that there can be a distance between the computer at the centre of the sound processing and where the action is. The music therapy space is best kept clear of electrical leads and this is especially important with users that are unable to reach a computer or their equipment prevents them from easily accessing wired devices. Some equipment vital to some CYP or wheel chairs do not easily travel over wires and for others having the computer and its screen nearby can provide distractions. However, there is danger of adding complexity to the system and opportunities for technical failure by making things wireless.

16. Think of the whole context – Designing a DMI in itself is a challenge but when this design process is placed in a school setting it can be even more challenging. There is a need to find out how best to communicate with those involved and how to disseminate what you are creating. The school environment may restrict what can be done, with the time of day and year affecting the ability to access the users. Very often instruments designed are not accessible or configured by the target users directly but by those facilitating access. There may be several practitioners involved in the use of the technology; from music leaders to music therapists, to teachers and teaching assistants all with various goals. Sessions could focus on "education in music, education through music, music therapy, or music as a leisure activity" [6 p11] with goals to play as an ensemble, to feel a sense of intimacy with an instrument [21], to provide a therapeutic or educational experience, or playing for fun. There is a need for user friendly systems that understand requirements and attitudes of facilitators in order to be inviting to use [7]. Often DMIs developed for the school setting are taken away when the research finishes, "leaving something behind is preferable as is keeping the tech neutral with no brand, open source and widely available" [32]. If DMIs are taken away there in no opportunity to practice with the instrument removing the chance to progress.

17. Providing educational context for use – One of the larger problems, certainly for the uptake of technology within the area of music therapy, is incorporating technology into practice [33, 5] and having confidence with doing so [7]. Cevasco and Hong [34] suggest giving provision to providing examples of how to incorporate technology into practice with better training on how to enhance music making with technology to make it less daunting. Linking with requirements of the curriculum, learning outcomes, or other curriculum subject areas can also be useful at showing the spectrum of how the technology can be put into practice. Frameworks such as the Sounds of Intent [35] have made progress in this area. This can create a context for use especially if linked into teaching schemes. If teachers and facilitators cannot see how the technology can be put into practice they may leave it on the shelf.

18. Tech and do you even need it? – Technology should be unique to an individual's needs [32]. and not just be used as "technology for technologies sake" [11 p151]. Bott identifies that a key issue to consider when determining musical possibilities for individual musicians is to try and distinguish between: a) Access Needs, and b) Learning Needs [6]. For physical barriers, the emphasis of provision should aim to maximize individual physical abilities and for cognitive barriers, an emphasis on tools that adapt to the individual's cognitive level should be paramount. The technology should primarily meet the creative preference of the musician [6]. Stakeholders from the Three Ways School say technology can also be combined with acoustic instruments by using this interplay to encourage motivation, interaction, and engagement [personal communication].

6. IMPLEMENTATION EXAMPLE

Following is an example of the design considerations in use as part of the EngD research leading to this paper. The research has used participatory design (13) to lead to the development of the modular accessible musical instrument (MAMI) system, which is in its prototype stage. The system will be described with numbered links to the design considerations which helped inform its design. Consisting of both hardware and software components, MAMI is aimed at providing a flexible way to create accessible instruments (1). The software component allows for connection of bespoke and existing technologies via various communication protocols (serial, MIDI, OSC or Human Interface) and for them to be mapped to musical parameters (9), or connected through to existing software (11). So far two bespoke instruments have also been developed to connect to the MAMI software: filterBox –a wireless handheld wooden box featuring a LDR, two buttons, and an FSR; and squishyDrum – a wireless circular wooden drum style enclosure with an elasticated fabric 'skin' which can be played by both deforming the surface and percussively hitting the enclosure (6). The development of these instruments is aimed at creating robust (7) wireless instruments (15) that inspire natural interaction (5) and are affordable to make (14), and easy to use for both the user and facilitators (16). Future work will look to; enable localised feedback (2,8); create graphical user interfaces that allow ease of customisation both in terms of sounds produced (12), expressivity offered (3), and level of user control (4); and to potentially add on-board recording (10). The system will be tested within an educational context (17).

7. CONCLUSION

This paper has offered 18 design considerations for instruments for users with complex needs in SEN Settings. With the aim of aiding DMI designers with the creation of new instruments and systems. The considerations focus not only on the instruments being designed, but also the system as a whole and the system in relation to the context of use. An implementation example is also given. When employed in practice these principles should be adapted to their contexts of use to allow for technology to be accepted and used, and to facilitate better access to music making not just for those whom technology provides an unparalleled access point to music, but also for those around them who facilitate the technology in use.

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10. Appendix 1

Stakeholders:
Three Ways school: Interactive designer Luke Woodbury, teachers Kirsty Hafford and Ben Edwards, music therapist Adrian Snell.
Victoria Education Centre: Music technologist Mike Whitlock.
Website for ongoing research: http://www.dotlib.org/