Bean: a Tool for Music Therapists

An Assistive Musical Technology for use in Music Therapy

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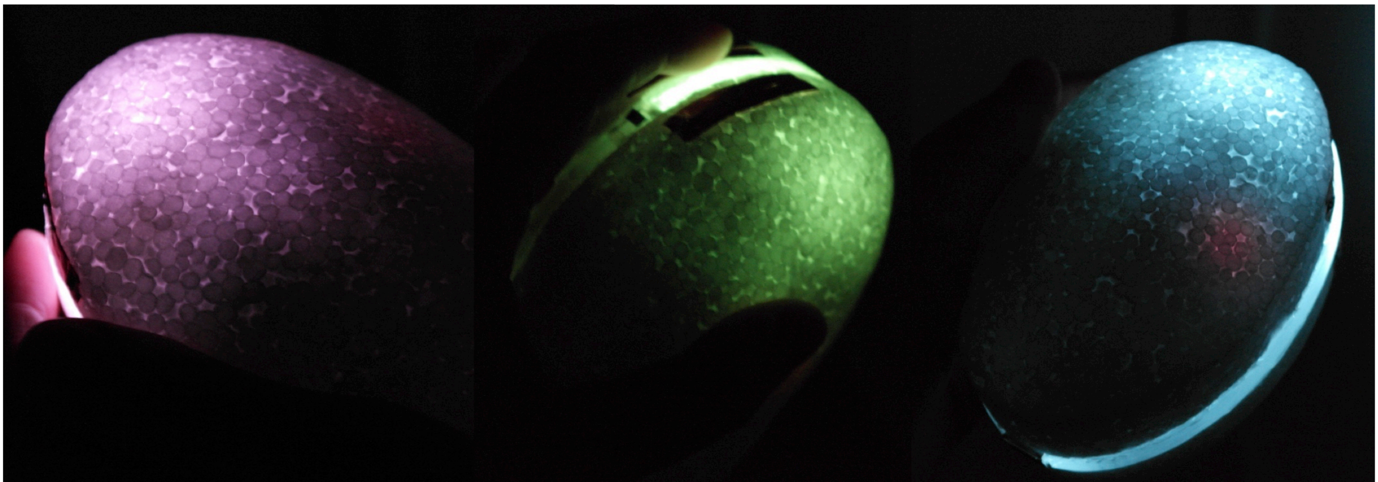

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Abstract

This thesis outlines the design and development process of an assistive musical technology: Bean, which was designed for use in a music therapy setting. This instrument is tangible in nature. An initial ergonomic design, guided by the principals of Inclusive Design, was created. Interaction with Bean is tangible with enactive traits. A modular structure, facilitated by rapid prototyping techniques such as laser cutting and microprocessor technologies such as Arduino, helped provide a flexible prototype for usability testing. A participatory, user centered evaluation of the prototype was carried out to primarily assess if Bean was simple and intuitive to use, and if it was relevant for use as a tool in a music therapy setting. Other aspects of the design were also assessed. A certified music therapist, several groups of clients with a variety of complex needs, family and staff members participated in the evaluation. Three test sessions were carried out over two days, with a total of 22 participants (13, 7 and 2 clients respectively). This evaluation resulted in the suggestion that Bean is in fact a relevant addition to the music therapist's tool kit. The majority of participants found Bean simple and intuitive to use, though with the caveat that Bean lacked some flexibility in use for those with complex physical needs. There was also a consensus that Bean was fun, and enjoyable in use.

Keywords: Tangible user interface, assistive music technology, music therapy, participatory design, enactive interface

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1 Introduction

Recently, the use of music related technology in a music therapy setting has become an emerging focus for research (Magee & Burland 2008; Hahna et al. 2012). The advantages of using music technology, particularly for those with complex physical, cognitive and sensory needs, in a therapeutic setting has been suggested to include: enhanced emotional expression, increased communication, and increased autonomy and motivation (Magee et al. 2011). The use of electronic music technologies (EMT's)[1] has been suggested to help offer a sense of empowerment, independence and achievement in a therapeutic setting (Burland & Magee 2012) This research gives a general, and valuable, insight into the current state of music therapy practice as regards technology use. However, as outlined in (Magee 2006), the use of these technologies is an underutilized resource. This underutilization holds particularly true for interfaces that facilitate tangible interaction. This is clearly suggested in (Farrimond et al. 2011; Magee 2006). It was found that the most therapeutically employed of these assistive music technologies uses non-tangible infrared distance sensing and simple push button switches as the main method for interaction.

There has been a wealth of research exploring tangible user interfaces (TUI) since Ishii & Ullmer (1997) first introduced the idea of migration from the graphic user interface to a more tangible alternative. More recently, specific research into TUI design, evaluation and use in a therapeutic setting has been carried out (Cappelen & Andersson 2014; Villafuerte et al. 2012). This research has shown promise for TUIs in relation to the facilitation of a sense of empowerment and increased social interaction. Nath & Young (2015) developed a ball shaped interface, which was designed to facilitate "group interactions" in a music therapy setting. The social aspects of music has been termed *musicking* in Christopher Small's book *Musicking: The Meanings of Performing and Listening* (Small 1998). This concept puts more weight on the interpersonal process and social ritual of music making, rather than the content or the nature of the music being played. This idea plays a central role in the work presented in (Cappelen & Andersson 2014).

[1] EMT's are defined in (Magee & Burland 2008) as electronic musical equipment using MIDI generated sounds which are triggered by specialist input devices such as switches or sensors. This is distinguished from general "music technology" such as digital audio workstations and microphones.

A more basic concern, compared to mode of interaction or social context, would be to find a suitable general design strategy for initial guidance. Universal Design is a design philosophy with the main aim of facilitating accessibility (Story 1998). However, the idealistic nature of Universal Design's one-size-fits-all style can be problematic in practice (Vanderheiden 1998). Inclusive Design is a branch of Universal Design which is more pragmatic (Clarkson et al. 2007). This design ethos is also practiced in human computer interaction (HCI) contexts (Mieczakowski et al. 2009). The vital alteration from Universal Design is the consideration of human diversity, and therefore acknowledging the possible need for flexible, diversity-supportive design to suit individual needs. Migrating from the Universal Design one-size-fits-all ideal towards the Inclusive Design 'one-size-fits-one' (Inclusive Design Research Centre 2010) ideal could be beneficial for assistive music technologies. Following on from an Inclusive Design perspective, individual knowledge of the users of such technology would be essential. Participatory design would be an ideal way to gather information, and *Informants* (Druin 2002; Guha et al. 2008) could provide this design information during an eventual evaluation setting.

Customized assistive technologies can be, for obvious reasons, problematic for some users due to financial considerations. With the blossoming of the maker movement (Dougherty 2012) together with fabrication techniques such as laser cutting, 3D printing and technologies stemming from microcontrollers such as the Arduino[2], the possibility of self-fabrication of interactive technologies has never been more accessible. There has been some research in the area of do-it-yourself assistive technology, making and 3D printing (Buehler et al. 2014). Buehler et al. discuss among other things, the interesting and positive possibilities of low cost fabrication of customizable assistive technologies. This could be an interesting direction of development for a low cost and customizable assistive music technology, created with the 'one-size-fits-one' ideal in mind.

A fitting evaluation framework for these customizable assistive music technologies would ideally be rooted in the practice of music therapists. The Individualized Music Therapy Assessment Profile: IMTAP (Baxter 2007) is a music therapy client assessment protocol. This system is based on different domains of development or

[2] Arduino is an open source microprocessor prototyping platform and integrated development environment. https://www.arduino.cc/

function, which can be of interest to the therapist. This flexible tool could be repurposed to help systematically evaluate assistive music technology, in a contextually relevant way, for use in a therapeutic setting.

This thesis will focus on describing the design, implementation and evaluation of a novel assistive music technology: Bean. Bean is designed for use in a music therapy setting. After researching the field of music technology use in music therapy, tangible interaction seemed to be a neglected interaction modality in mainstream technologies used in practice (Farrimond et al. 2011). As a result, Bean was developed to be tangible, with a view to providing the possible benefits of tangible interaction, and also an alternative to the current status quo. This tangibility was also influenced by an enactive approach (Armstrong 2006). Inclusive Design and User-centered Participatory Design have informed the design and implementation stages, with the aim of gauging the relevance, optimizing accessibility and facilitating simple and intuitive use. A qualitative evaluation was carried out with the co-operation of a music therapist and a group of clients with mixed abilities accompanied by family members and helpers. Along with a grounded theory based open coding analysis of the gathered data, the IMTAP has been adapted and used as an evaluation framework for the suitability of Bean in a music therapy setting. Above all, a primary aim in the development of Bean was to produce a fun, novel digital musical instrument, which could possibly add to the arsenal of tools available for the music therapist. The work presented here is a continuation and further development of (Kirwan et al. 2015), and a thread of continuity can also be seen following on from Interactive Musical Fruits (IMF) (Erkut et al. 2014).

The thesis will be structured as follows; the background section will outline the contextual and theoretical underpinning the design, development and evaluation described in this thesis. Technologies that are used in music therapy practice and/or are similar in some way to Bean will then be discussed in the related work section. The Concept behind the design will then be detailed in the next section. After this the implementation of both the hardware and software parts of the system will be explained. A description of the evaluation sessions will then be presented, followed by a discussion of the results. The conclusions obtained from this work will be highlighted, and finally the continuation of the development of Bean will be elaborated on in the future work section.

2 Background

Music therapy is an established health profession in which music is used within a therapeutic relationship to address physical, emotional, cognitive, and social needs of individuals. After assessing the strengths and needs of each client, the music therapist provides treatment including creating, singing, moving to, and/or listening to music (American music therapy association 2016). There is evidence that music therapy can have a positive impact on wellbeing throughout our life cycle. Musical interventions have proven beneficial in premature babies' feeding behavior, sucking patterns and increased quiet alert periods. These same interventions also helped reduce the perception of stress in their parents (Loewy et al. 2013). There is also evidence suggesting musical interventions can help alleviate pain symptoms in chronically and/or terminally ill adults (Kwan & Seah 2013). Levels of aggressiveness and anxiety in patients suffering from dementia have been likewise positively affected by musical interventions (Svansdottir & Snaedal 2006). As is evident from this research, the full range of possible therapeutic settings and positive effects of music therapy are vast, and consequently outside the scope of this report. The focus of this thesis regarding music therapy, involves adolescents and young adults with complex needs[3], including intellectual and physical disabilities.

A number of research projects investigated music technology use, with young people, resulting in both positive and negative implications. Meckin & Bryan-kinns (2013) give examples of both, which were concluded from a relevant literature review. In relation to the positives for example they suggest, the use of alternative input technologies in music therapy settings with people with complex needs can reduce feelings of isolation and increase those of self-accomplishment. However, the uptake of these technologies in practice is low, in 2003 as low as 2% of students with complex needs had access to assistive music technologies (Meckin & Bryan-kinns 2013). Magee (2006) found that only 30% of the music therapists surveyed had used music technology. 18% of those surveyed stated they did not like technology, and 4% went further to state they felt music technology was not appropriate or relevant to music therapy. Acceptance of music technology in music therapy can be seen to have changed positively since 2006 though. Hahna et al. (2012) found, through a

[3] In the scope of this thesis, complex needs is defined as an umbrella term, which refers to cognitive disabilities and/or physical disabilities.

geographically broader survey in 2010, a significant increase in technology use to 71% of those surveyed. While the survey suggested the majority of music therapists have a positive outlook on music technology use, some therapists continue to work without these technologies. There were a number of reasons suggested by this survey as to why 29% of therapists still did not use music technologies. These include: lack of money, lack of training, lack of portability and some felt it was not appropriate in music therapy. Taking these issues into consideration during the developmental process of an assistive musical technology could prove beneficial to eventual uptake by as many therapists as possible.

Financial considerations are commonplace in regards to assistive technologies. (Farrimond et al. 2011) mentions the idea of 'economies of scale' as a reason for the high cost of music technologies that are developed specifically for those with complex needs. An example is mentioned where one such technology, a midi keyboard, was priced at £1200, while a comparable consumer grade keyboard could be bought at the time for approximately £31. Despite the extra functionality of an enlarged interface and added touch sensitivity, it is hard to see a justifiable reason for such a large price difference between the two. From a purely financial standpoint, self-fabrication could help alleviate this issue (Buehler et al. 2014).

A perceived need for specialist, music technology training for music therapists has also been mentioned in several studies (Magee 2006; Hahna et al. 2012; Farrimond et al. 2011) as a possible hindrance in technology uptake. Indeed these thoughts are echoed in (Streeter 2007), where it is suggested that the complexity of assistive music technologies such as MIDICreator (Kirk et al. 1994) could be a source of disillusionment. The 78-page user manual and 'configuration building software' give the impression of over complexity, before the system is even used. It is therefore suggested by Streeter, that some therapists would not have, or spend, the time to learn how to use such a system. It should be mentioned though, that even since 2007 there has been a large increase of daily Internet use by adults in Great Britain from 45% to 78% in 2015 (Office for national statistics 2015). It is perhaps not unreasonable so, to think that widespread smartphone and tablet use and almost ubiquitous Internet access, would help generate greater acceptance of the use of other technologies. Furthermore, an intuitive and straightforward system could facilitate use by therapists who have a general understanding of information technology, but do not have direct training in music technology.

An issue with lack of portability is also one, with current technical possibilities, that has become moot. Modern laptop and tablet computers are highly portable and wireless technology removes the need to carry a lot of cables to connect discreet devices of a system together. A lack of portability seems to apply to existing systems, which are perhaps showing their age.

The most problematic of the reasons for not using technology mentioned here could be the negative attitude of the therapist. Unfortunately, there may always be therapists who are of the opinion that these technologies are not appropriate, and indeed, they are entitled to that opinion. The research however (Magee et al. 2011; Meckin & Bryan-kinns 2013; Farrimond et al. 2011), suggests that they are very much appropriate, and have something to offer in a music therapeutic setting. Therefore more investigation is merited, despite the opinion of the minority. Moreover, the music therapist can be a valuable source of information, due to practical experience, and contribute to the development of these technologies in a participatory setting. In fact, musical assistive technologies for use in music therapy could be seen to have two target groups, the clients who would use them and the therapists and staff who would need to facilitate the clients in use. Both of these groups could have insights, which would contribute to a final design.

2.1 Inclusive Design

In the initial design stages of Bean, a participatory input was not available. Therefore, the design was informed by more general design philosophies. A prevalent philosophy focusing on the facilitation of accessibility is Universal Design (Story 1998). Universal Design was first seen as a concept in architecture in the 1950's, where a *barrier free* design ethos was used to make buildings more accessible to everyone (Moore 2007). A continuation of this awareness was said to have become a cornerstone for design practices in fields such as architecture, civil engineering, and human factors engineering (Moore 2007). While at first glance Universal Design may seem a perfect guide in the creation of assistive technologies, there is however a clash in ideologies here. Universal Design with its origins in architecture, strives towards a single solution for users of all ages and abilities, without adaptation. Assistive technologies however are generally individually tailored to suit the user's specific needs. Vanderheiden (1998) outlines these conflicting ideas, and suggests a Universal Design model that is also open to the use of assistive technologies.

Inclusive Design includes Universal Design guidelines, along with the pragmatic acceptance for the possible need of assistive technology. It is defined as design that considers the full range of human diversity with respect to ability, language, culture, gender, age and other forms of human difference (Inclusive Design Research Centre 2010). Inclusive Design therefore seemed to be an ideal starting point to inform the initial design choices in the development of Bean. The principals of Universal Design (Story 1998), provide a general guide with accessibility in mind, and could also be interpreted as Inclusive Design guidelines. These principles (

Table 1) are of course broad in nature, generally informing any design towards an inclusive goal. Focusing on the design of Bean, some of these principals were more relevant than others. For instance the first four and the sixth are extremely relevant to the usability of Bean in an inclusive context. The other two principals seem to be remnants of Universal Design, more focused on an architectural design than product design. However, the points made in these two principals still make sense, and should still be kept in the back of the mind.

Table 1 The Universal and Inclusive Design principals (Story et al. 1998)

Principals of Inclusive Design		
1	Equitable use	*Useful and marketable to those with special needs*
2	Flexibility in use	*Accommodate a wide range of individual preferences and abilities*
3	Simple and intuitive use	*Easy to understand regardless of the users abilities*
4	Perceptible information	*Communicates the necessary information effectively to the user*
5	Tolerance of error	*Minimizes hazards and the consequences of accidental actions*
6	Low physical effort	*Can be used efficiently and comfortably with a minimum of fatigue*
7	Size and space for use	*Appropriate space is provided for reach, manipulation and use*

2.2 Participatory design

There are many theories related to participatory design, but the research that has informed the participatory process described in this thesis will be outlined here. The framework found in (Druin 2002), suggests 4 roles a child can play in the design process: *user, tester, informant* and *design partner*. These roles describe the level of participation and when in the process the children are involved. The *user* for instance would be the least involved in the design process, using the final product under observation for final usability testing. Whereas the *design partner* would be the most involved in the design. They would be seen as equal stakeholders and contribute throughout the development process. The role of *informant* would best describe the participatory input gathered during the evaluation of Bean.

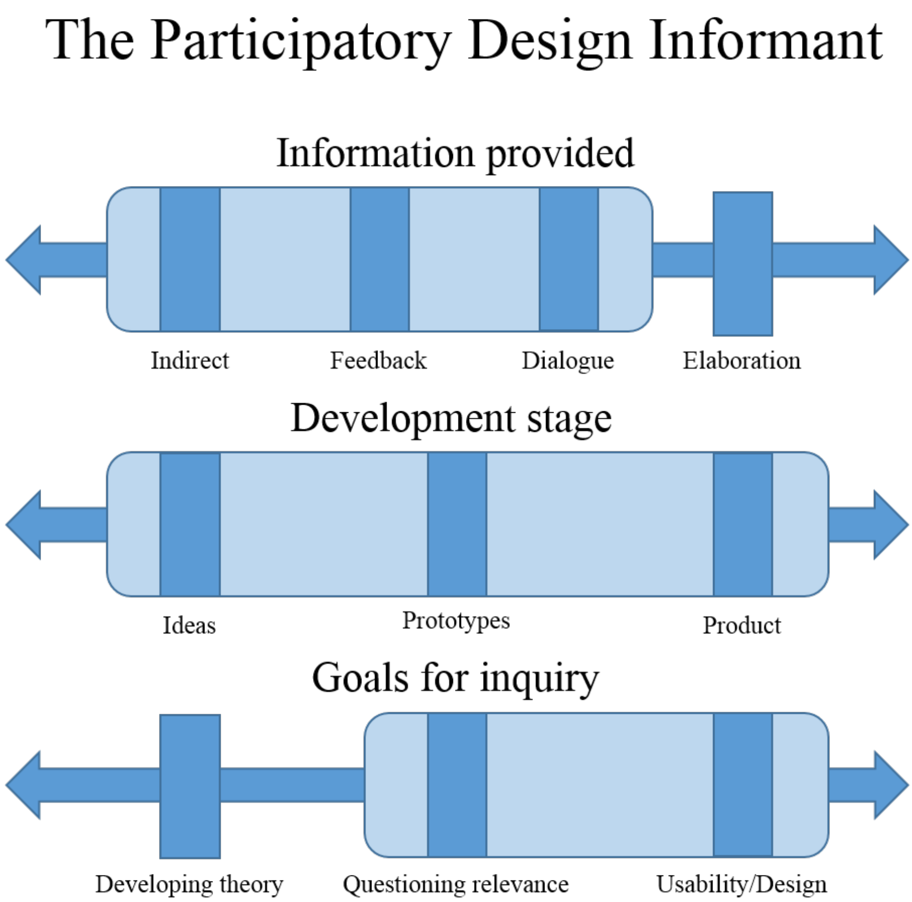

Figure 1 The informant role, Based on Druin's participatory theory.

Druin posits that the type of information provided by *informants* (Illustrated by the top shaded rectangle in Figure 1) can include *indirect* information from video observation. Direct written or verbal *feedback* and *dialogue* about their own design ideas. An *informant* can provide information at all stages of development (Middle shaded rectangle in Figure 1). That is, from initial idea generation to testing at the prototype stage, to eventually evaluating a final product. The goals addressed when participating at the *informant* level are suggested to include the *relevance of the product*, and *usability/design testing* (Bottom shaded rectangle, Figure 1).

Guha et al. (2008) present a further development of Druin's work, directly aimed towards an inclusive model of participatory design. The *inclusive model* considers specifically children with complex needs and the challenges that may arise during participatory design sessions. Here, along with the levels of involvement shown in Druin's framework, personal helpers and aids are also included. This idea was further explored through the development of moosikMasheens, where Meckin & Bryan-kinns (2013) included staff and teachers in the participatory design process of assistive music technologies. This inclusion was judged to be *"essential to gain understanding of real-world use situations"*. It was also mentioned that both the students and the staff acted as *informants* according to Druin's roles (Meckin & Bryan-kinns 2013). The evaluation of Bean will make use of *informants*, to gather *dialogue* and *feedback* about Bean, along with *indirect* observation of interaction with Bean in order to assess the *relevance of the product*, and *usability and design.*

2.3 Tangibility

The Inclusive design principals presented above (Table 1) are general in nature, and while they provide a good starting point, when the design becomes more focused on certain specific aspects, the source of informed decisions must be found elsewhere. Early in the design process the decision on tangibility was made. This was partly due to the lack of an intrinsic tangible element in prevalent assistive music technologies (Farrimond et al. 2011) that are used in music therapy, and partly because of the positive aspects suggested in the literature. Such as, tangible systems tend to support collaboration and social interaction (Hornecker & Buur 2006) and encourage discovery and participation (O'Malley et al. 2004).

Ishii & Ullmer (1997) presented a compelling argument for research into tangible interaction. The lack in *"embracing the richness of the human senses"* in twodimensional traditional graphic user interfaces could be said to be even clearer when the interaction is musical in nature. In traditional musical practice, tangibility is inherent in the physical act of playing an instrument. Through this tangibility a direct physical action to sound production link is facilitated. Leman (2012) suggests that interactive musical systems *have "both a technological and experiential component"*. This experiential component, when speaking of gesture controlled musical interfaces, could be related to an embodied interaction approach. This approach was explored, specifically through tangible artifacts, with children in (Bakker et al. 2012). Bakker et al. investigated action to sound metaphorical links, and found that tangible systems *"provided clarity in interaction"*. On a personal note, a feeling that a tangible interface would help to add a tactile and visual focal point for the interaction was also a factor in the choice of a tangible design.

When speaking of a tangible musical interface design, it is worth mentioning a relevant body of research, which focuses in part on this topic, and has had influence in both the conceptual and practical development of Bean and the prior IMF. Lyons & Fels (2014) gives a comprehensive outline for the creation of New Interfaces for Musical Expression (NIME). NIME provides a multi-level framework that helps facilitate the creation of expressive musical interfaces. Although this framework encompasses many detailed areas of research, for the purpose of the description here it can be roughly broken down into four main areas of focus: Sensors, Mapping, Synthesis and Demonstration. In essence the NIME could be seen as a bottom up design method, focusing very much on the technological and less so on the experiential. This point is in fact highlighted in (Andersson et al. 2014), bemoaning the focus on a *"tool-oriented cause-and-effect"* approach in NIME, in favor of a more social and experiential focus on *musicking*. That is, the idea of *"potential relations between persons, their experiences of music, and activities of all sorts of music making"* (Small 1998). Perhaps a middle ground, using aspects from both of these approaches could be mutually beneficial.

2.4 Enactive

Armstrong (2006) presents a compelling experiential centered approach to the design of digital musical interfaces. Based on the embodied 'enactive cognitive science', presented in chapters 8 and 9 of (Varela et al. 1992), Armstrong's work was driven by the 'disconnect' between computer music practice and the more human motor centric engagement of traditional music performance. He also states there is a lack in *"first person phenomenal experience"* in *"computer as it comes"*[4] music performance. This enactive design approach is deeply rooted in embodied cognition, that is to say, cognition *"arises through and within an agent's physical interactions with her environment"* (Armstrong 2006). Armstrong suggests a number of interaction design criteria for digital musical instruments, based on an enactive approach, which are summarized below:

Embodied activity is:	*Situated*	The interaction occurs within an environment.
Embodied activity is:	*Timely*	The interaction occurs in real time.
Embodied activity is:	*Multimodal*	The interaction is multisensory in nature.
Embodied activity is:	*Engaging*	The activity depends on user interaction.

The sense of embodiment is an emergent phenomenon: The experience is the product of the activity over time.

Interestingly, and to some extent related to Leman's (2012) earlier mentioned experiential component, the enactive approach does not rely on cognitive constructs such as conceptual metaphor or other symbolic tools[5], for the description and mediation of these experiences. Instead, repeated "*sensorimotor interaction between the agent and the environment*" form the fundamental experiential representation of the enactive perspective (Armstrong 2006). Relating this back to interface design, and specifically Bean, one of the most interesting points to take from an enactive approach, is a design of an optimal method of control, which does not hinder the flow[6] of an enactive interaction. This would in turn imply the use of innate skill sets, rather than acquired[7], for the purpose of controlling Bean.

[4] *"Computer as it comes"* performance seems to relate to musical performers such as the Princeton Laptop Orchestra. http://plork.princeton.edu/index.php

[5] A comprehensive description of such symbolic reasoning can be seen in (Lakoff 1993)

[6] The term flow, defined in (Csikszentmihalyi & Csikszentmihalyi 1992), describes an intrinsically motivated or autotelic activity (auto = self, telos = goal), which is an activity rewarding in and of itself, separate from the end product that might result from the activity.

[7] Acquired here can be understood in the context of practicing a traditional musical instrument, and the idiomatic skill set this requires.

In (O'Modhrain 2007) the *tangible-enactive space* (Figure 2) is created to assess the *enactiveness* of a number of tangible interfaces. Two of Armstrong's criteria were used as axes in the creation of this space, these are: *Timeliness* and *Engagement*. The lack of the other criteria in the space was explained as follows:

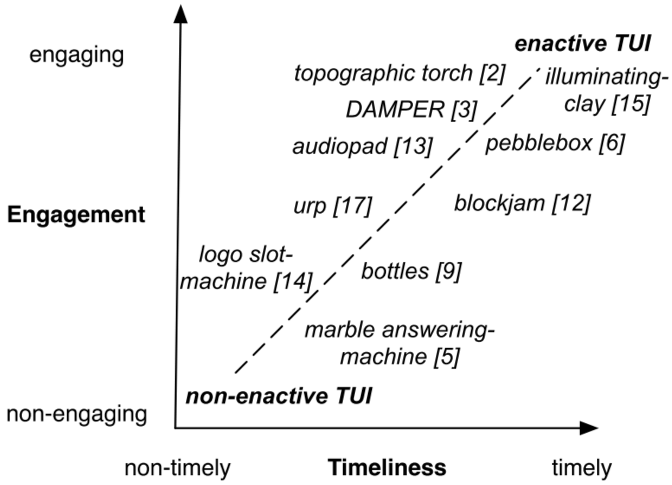

Figure 2 The tangible-enactive space (O'Modhrain 2007)

The first four criteria were judged as design specific, while the fifth was considered more as the result of an enactive system and therefore disregarded. It was suggested by O'Modhrain (2007) that all TUI's are in fact *situated* due to their tangible nature. It is also suggested that TUI's are generally *multimodal* in nature, with the primary tactile interaction usually augmented with visual and/or aural feedback. The largest variation found in TUI's in relation to the enactive criteria lies in both the level of *engagement* needed in interaction, and the level of *timeliness* or latency in the system. Therefore, the *tangible-enactive space* made use of those two criteria. While reviewing this research a question arose; would Bean enable enactive interaction according to the logic of the *tangible-enactive space*?

2.5 Machine learning

Embodied tangible interaction generally involves gesture of some sort. A recent promising development in HCI, regarding real-time gesture recognition, is the use of machine learning (ML) algorithms. Caramiaux & Tanaka (2013) present a comprehensive overview of ML techniques and their application in interactive music and new digital instrument design. ML is described as a body of statistical analysis that achieves tasks by learning from examples (Caramiaux & Tanaka 2013). Most gesture recognition systems output results in discrete time, typically upon gesture completion (Caramiaux et al. 2013), which can be problematic in relation to the continuous nature of the variation in expressive gesture. To tackle this problem, Caramiaux et al. (2013) present the Gesture Variation Follower (GVF), which has the ability to track changes in a learned gesture during continuous interaction. The GVF has been released as an open source Max/MSP[8] toolkit. For a more technical description of the specific statistical techniques used in the GVF to facilitate this continuous recognition see Chapter 8 of (Caramiaux 2012). There is clearly enormous potential in the use of ML in the design of digital musical instruments, due to an added layer of adaptive processing, which allows for a more nuanced feedback from an interactive system. A 'work in progress' implementation using GVF has been created for Bean, and while promising, it was not ready to used in the evaluation due to time constraints. There has however been continued work on it since, and a description will follow in the future work section.

2.6 IMTAP

After describing aspects that are relevant to the design, functionality and experiential matters of digital musical instruments, this section will bring the focus back to the therapeutic context we mentioned earlier. The Individualized Music Therapy Assessment Profile is a clinical tool produced for use in pediatric and adolescent settings. It is a systematic protocol, using ten *"domains of functioning"* (Baxter 2007).

Table 2 The IMTAP domains and sub-domains

Domain of functionality	**Areas assessed**	**Examples of Sub Domains**
Gross motor	*Movements, which includes the larger muscle groups, limbs or whole body.*	Muscle tone
		Right/left dominance
Fine motor	*Movements with the smaller muscle groups of the hands and fingers.*	Grasp
		Finger use
		Alternating hands
Oral motor	*Oral muscle structures.*	Vocalization
		Eating
		Air production

[8] https://github.com/bcaramiaux/ofxGVF

Sensory	*Responses to, tolerances of and integration of various sensory modalities.*	Tactile
		Aural
		Visual
Receptive communication	*Awareness, perception and reaction to aural stimuli.*	Musical changes
		Singing
		Rhythm
Expressive communication	*Verbal and non-verbal communication skills.*	Gesture
		Vocalization
		Verbalization
Cognitive	*Mental processes and functions.*	Decision-making
		Direction following
		Counting /Reading
Emotional	*Emotional states.*	Expression
		Regulation
		Self-awareness
Social	*Interaction and communication with others.*	Participation
		Turn-taking
		Relationship skills
Musicality	*Response to various musical mediums and the desire to participate in each*	Creativity
		Music reading
		Accompaniment

These domains can be chosen to fit specific therapeutic tasks, providing a flexibility to this assessment protocol. The ten domains and examples of their respective sub domains are presented in Table 2, containing the essence of how they are described in (Baxter 2007). These domains are used as part of a scoring system and archiving software in order to quantitatively track a client's longitudinal progress. However, the IMTAP domains will be used here as a framework to guide the evaluation in order to contextually assess the current state of the prototype, and guide towards relevant potential further developments. Also, the domains will be used in order to compile mini case studies, thus helping to provide portraits of the interaction scenarios created by some of the participants during the evaluation.

3 Related work

In this section musical assistive technologies and other relevant technologies will be presented. How they relate to this thesis and their functionality will be elaborated on.

Bean

An earlier iteration of Bean (Figure 3 left) is described in detail here (Kirwan et al. 2015). I will briefly review some of the developments since. The method of interaction in this version is very similar to the current design, with movement being the primary mode of interaction. The internal construction however has been greatly developed. In the earlier iteration, a commercial game console remote was hacked and controlled by a microcontroller. The idea behind using this remote was to provide a low cost solution. While this solution worked, it was not ideal. The current solution provides much more accuracy and flexibility in obtaining orientation data. The earlier iteration was also tethered with a USB lead to the laptop to facilitate data transfer and power. This has now been developed with wireless data connection and a rechargeable battery to supply power; both of these developments provide a greater possibility for free movement scenarios.

IMF

The interactive musical fruit (Erkut et al. 2014) (Figure 3 right) can also be directly related the development of Bean. While the focus of this project was in another direction, the method of interaction is very similar. Movement was employed as the primary interaction mode and it was used to control three types of musical content. These *"fruits"* were designed to enable a broad audience to interact with music, without necessarily having prior musical skill or experience. This ethos, while more directly relating to those with complex needs, can be seen as a recurring theme in the development of Bean. An approach underpinned by the study of tangible and embodied interaction was undertaken in the design of these interactive musical fruit. These ideas can also to some extent be seen in this thesis, again modified to focus more on those with complex needs.

Figure 3 Test sessions with Bean (left) and IMF (right)

Soundbeam

Soundbeam (Swingler 1998) is a commercially available assistive music technology. It was originally created for use with dancers and later adopted by the special needs education and music therapy communities. A number of studies to date have found that Soundbeam is in fact[9] the most prominent assistive music technology in use in music therapeutic and special educational needs situations (Magee 2006; Magee & Burland 2008; Farrimond et al. 2011). This technology relies primarily on ultra sound sensors. The motion detection can be scaled in a way that opens many possibilities of musical interaction for those who for instance have limited movement abilities. The linear motion captured from each ultrasound sensor is then translated into MIDI messages. These messages can then be routed to make synthesized sounds. There is also the possibility to use input from switches in this system, which can be seen as rudimentarily tangible, but it could be argued, not in the way Ishii & Ullmer (1997) defined TUI. Soundbeam has an inherent abstract method of music generation. This intangibility could contribute to a lack of a focal point in an interactional sense, and possibly be difficult for some clients to understand. There are case studies, which suggest this is a possible scenario (Rasar 2010). If this is in fact the case, Bean could possibly prove a more tangible alternative.

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[9] It is worth noting that these studies focus on special needs education and music therapy practice in the United Kingdom. (Hahna et al. 2012) found similar results in a more wide-ranging survey in 2012. These are the most current findings on the subject.

MIDICreator

MIDICreator (Kirk et al. 1994) was created specifically for use in music therapy. It is a standalone MIDI generating module with a number of inputs for a variety of transducers and switches, and MIDI out for connection to a sound module. A strong point for the use of MIDICreator was the diversity of sensors that could be used to capture client interaction. In 1999 an updated model was released. The MIDICreator+ had a built in sound module negating the need for extra cables and sound modules. There was no user interface on MIDICreator. Therefore, the only way of changing the internal settings was through the use of 'config cards'[10]. Magee (2006) found during her survey that this technology was the second most popular assistive music technology in a music therapy setting, and this is why a description of it appears here. However, this device is no longer in production and although it was state of the art at the time, the system is inevitably technologically dated at this stage.

Skoog

The Skoog is one of the few commercially available tangible assistive musical technologies. This innovative interface attempts to remove the *"barrier of dexterity"*[11] with a colour-coded, multi-touch surface that is soft and squeezable. The Skoog is designed to be played on a desktop or stand mounted. It can be squeezed, twisted, tilted or touched on the outer multi-touch surface to play. USB or Bluetooth must be used to connect it to a computer or tablet, where varied and intuitive sound generation is facilitated by an app on the computer or tablet. MIDI capability is also a feature. Movement sensing is however not a feature on the Skoog.

Motus

The Motus is a novel commercially available device for sensing movement. It comes in a very small package, and translates movement into MIDI or OSC. There is an accompanying app, which runs gesture recognition algorithms and processes the MIDI or OSC output. The only mode of interaction is through movement and gesture, there is no other direct means of controlling. The Motus is mentioned here because of the similarities in the method of interaction compared with Bean. To this date there is

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[10] http://www.applaudinteractive.com/exploring-the-store-cupboard/

[11] http://skoogmusic.com/education/#inclusive

no documented use of Motus in a therapeutic setting, however it's potential in relation to facilitating gross motor music therapy interventions is apparent.

Vesball

Coming from a NIME[12] perspective, Vesball (Nath & Young 2015) is an interesting device. With embedded processing and sound production, Vesball is designed to facilitate musical expression and ensemble musical play. The authors found it challenging in this study to strike a balance between practicality and functionality. They suggest a single design solution cannot be generalized to suit different therapeutic needs, and in order for the device to be successful, the therapist music be integrated in the design process. This advice about design flexibility and therapist inclusion was integrated into the developmental process of Bean.

MO

Speaking of design flexibility, Rasamimanana et al. (2011) present a modular set of tangible objects for sound control. The central wireless object is gesture controlled and wireless. This module could then be added to with passive or active accessories. One example of a passive accessory was a rubber football. The active accessories were still in development at the time of publication. Apart from similarities in the technical implementation to bean, the authors mention an interesting 'bottom up' design approach. Their description of this approach favors a more user-friendly approach and could be also seen as participatory in nature [13]. The developmental process of Bean has many of the same traits. Particularly the modular nature of the design is interesting in relation to the design of Bean. As a side note, the technology in MO has since been commercialized, using the name *Phonotonic.*

Reactable

Reactable (Jordà et al. 2007) is a popular tabletop tangible interface. Originally a research project, the Reactable is now a commercially available product. The reason Reactable appears here however is the research found in (Villafuerte et al. 2012). Villafuerte et al. document the assessment of Reactable for use in a music therapy

[12] http://www.nime.org/

[13] The authors mention *user-completed systems* to describe an alternative to the non-modifiable product that must be adapted to by the user, which in their opinion results from "top down" design.

setting. Their focus group is children with autistic spectrum conditions, and their goal is to evaluate the effectiveness of Reactable in helping with the acquisition of social abilities. This paper offered an interesting insight into the possibilities TUI's can provide in a complex needs scenario.

moosikMasheens

moosikMasheens (Meckin & Bryan-kinns 2013) are a set of electro-mechanical instruments specifically designed for young people with complex needs in order to enable musical expression. Although the technical implementation of the instruments is not hugely relevant, as the instruments differ fundamentally from Bean, the theoretical background and design process has been very influential and is indeed very relevant to the work presented here. The inclusive participatory design process Bryan-kinns and Meckin underwent during the development of moosikMasheens proved a source of inspiration.

RHYME project

Andersson & Cappelen (2013); Cappelen & Andersson (2014); Andersson et al. (2014); Stensæth (2013) describe, from different points of view, *"co-creative tangibles"*. These *"tangible smart things"* were designed to provide children with disabilities and their families an interactive musical experience with the aim of promoting health and well-being. A recurring theme throughout the project was the view that music is primarily a social *"doing"* rather than a reified *"being"* or object (Stensæth 2013). This idea is directly related to Small's *musicking* (Small 1998). This point of view is very interesting, particularly in a music therapy setting where the relationship between the client and the therapist is paramount. Changing the focus from the negative perception of a lack of quality or skill in music performance, to the positive influence music has interpersonally, could help improve feelings of empowerment (Andersson & Cappelen 2013).

4 Concept

The underlying idea throughout the development of Bean was to create a scenario of fun and accessible music interaction, facilitated by technology. Moreover, Bean should be suitable for use in a therapeutic setting. With this in mind, it was determined that the therapist should be an active member in the design process and along with prospective clients, would be ideal *informants* to help shape and refine any such tool. After reviewing the literature (Magee 2006; Magee & Burland 2008; Magee et al. 2011; Farrimond et al. 2011; Hahna et al. 2012), and speaking with a therapist, it was clear that any such tool should be flexible in nature. The most popular examples of assistive musical technologies are, to varying degrees, adaptable to different levels of intellectual and physical abilities. This was also therefore a goal during the development of Bean.

There are two levels to this adaptability. The first is the combination of hardware and software to enable interaction that is easy to understand. A "*low entry fee with no ceiling on virtuosity"* (Wessel & Wright 2002) comes to mind here. When relating this directly to Bean, the facilitation of virtuosity is not relevant due to the context of its use in music therapy, with people with complex needs. However, having a *low entry fee* (simple and intuitive to use, in other words) is crucial. Multimodal feedback is also a feature that would be implemented to aid in this transparency. Transparency in this context can be defined as an easily understandable connection between action and audible change (Kirwan et al. 2015). Movement arbitrarily affects the colour of the light, while this *"cause and effect"* (Magee et al. 2011) transparency would be facilitated in part by the visual cueing of the light turning on and off during interaction. These interactions would be gesture based with a tangible focal point. Aside from a focal point for engagement, the tangible user interface would also ideally provide the opportunity for an embodied musical experience, possibly resembling that described in the enactive approach mentioned earlier. Looking to future work, this embodied tangible approach could also possibly provide a longitudinal physical performance and diagnostic tool for a therapist if the suitable software was created.

The second level of this adaptability is of a more practical nature. When considering clients with physically complex needs[14], flexibility in the physical shape of Bean could make the difference between ability and inability to use the technology. The first step in facilitating this physical flexibility would be a modular construction. This construction could consist of a central module that contains the electronics, which would provide the processing power for Bean. The outer casing could then be customized to better suit clients with complex physical needs. Again looking to future work, by making use of 3D printed self-fabrication techniques, the customization of assistive music technology could become more realistic both practically and financially. Thus enabling more clients to have tangible embodied musical experiences in a therapeutic setting.

On a more socially experiential note, the ideas expressed in (Small 1998) are central here also. These ideas, applied to tangible interface design for people with complex needs, have been realized in (Cappelen & Andersson 2014). A high quality of music, from an aesthetic point of view becomes secondary to enabling the process of music making from a social and ritualistic standpoint. That is not to say that the aesthetics are not important. An aim here would be that both the aural and visual aesthetics could function to generate interest and ideally motivation to use Bean. Nonetheless, in a therapeutic setting, music is essentially used as a tool to facilitate the relationship between the client and the therapist. Therefore, the focus on enabling *musicking* on any level, from as many clients as possible, played a central role in the conceptual composition of Bean.

[14] A complex physical need could be, for instance, trouble with grasping Bean in the basic ellipsoidal shape that is seen in (Kirwan et al. 2015).

5 Implementation

This section will outline the implementation of the prototype Bean. The initial design and iterative design process, which resulted in the prototype, will be discussed. The hardware, software and physical construction will also be described.

5.1 Initial design and Iterative stages

As mentioned earlier, this thesis documents the further development of (Kirwan et al. 2015). After the decision to make Bean tangible was taken, an initial design was made. There was some consideration on the initial shape, and it was decided to make it ellipsoid. This was an attempt to produce a physically ergonomic shape, similar to the ideas expressed in (Hatanaka 2003), that suited the hands comfortably during two handed interaction (Kirwan et al. 2015). It was then decided that the flexibility of being able to choose either one or two-handed interaction would be of benefit. Therefore the size of Bean was reduced to also enable one-handed interaction. The materials used at this initial stage were considered because of their practicality. In Figure 4 you can see the images of the iterative development of several prototypes since the initial (far left) described in (Kirwan et al. 2015).

Figure 4 Iterative steps in the development of Bean

These iterative steps were necessary to shape and improve the interaction possibilities with Bean. In the middle bottom picture of Figure 4 the capacitive touch setup was being tested and added. In (Kirwan et al. 2015) the design had two pushbuttons for additional interaction possibilities. These buttons were revised in this newer iteration, and are now capacitive touch pads. This was also an attempt to promote simple and intuitive use, thereby eliminating the need to use force (although it was minimal) to depress a physical button.

In the top middle picture of Figure 4, the capacitive touch was refined and the size was reduced to facilitate one-handed interaction as well as two. Polystyrene foam was used to fabricate the outer shell. The idea behind this was to help protect the electronics from a potential drop while in use. On the right of Figure 4 we see the final prototype that was used in the evaluation. This iteration added a laser cut acrylic plate. The outer polystyrene foam is not a robust material, but performs very well in impact reduction. The reasoning behind this plate was to provide a modular base for mounting the electronics, so that the outer shell could easily be replaced if damaged after being dropped. An added functionality of this acrylic plate was help diffusing the light from the LEDs.

5.2 Multimodal Feedback

Bean is multimodal in nature. The three modalities involved in interaction with Bean are aural, visual and tactile. The tactile interaction would be classed as passive in nature, as it is Bean itself that is the tactile element during interaction. There is no implementation of vibro-haptic feedback in Bean currently.

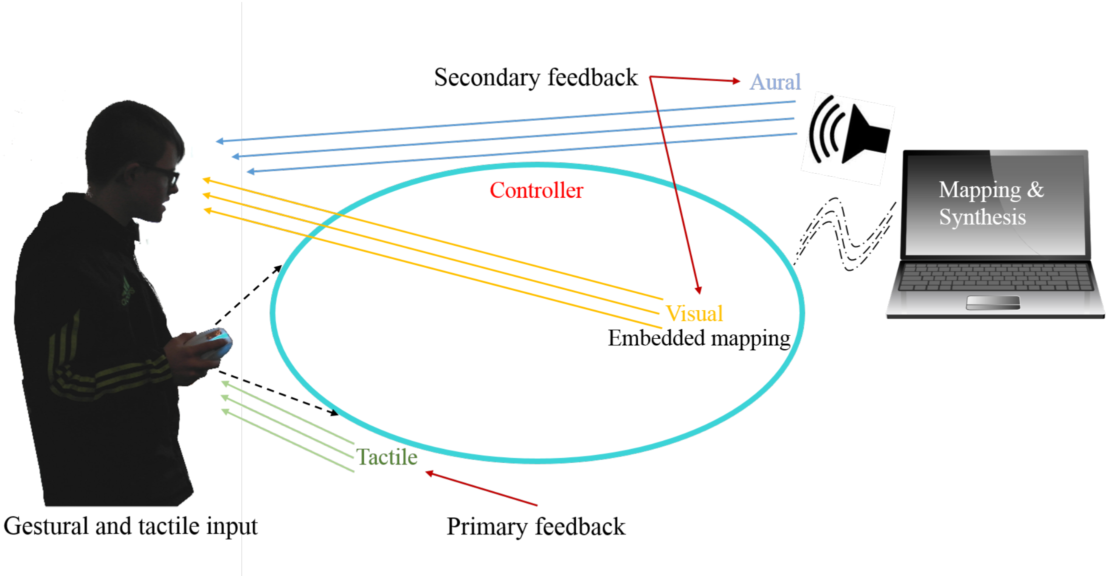

Figure 5 Both primary and secondary feedback are involved when interacting with Bean

Both the aural and visual feedback is considered active in Bean. That is, the content and state of both aural and visual feedback is altered through interaction with Bean. In Figure 5 a visualization of the system in relation to multimodal feedback can be seen, this visualization is based on the NIME model found in (Lyons & Fels 2014). In the following sections both the aural and visual feedback will be described. The mapping strategy of each feedback modality will also be described in more detail.

Aural Feedback

The aural implementation of the prototype for the evaluation was simplistic in nature. A single octave of pentatonic notes was available to play. The pentatonic scale was chosen for this initial implementation, because of its forgiving nature in relation to harmonic accompaniment. For instance, any note of the C pentatonic scale, will 'fit' (be melodically consonant) when an accompaniment plays the primary chords of the C major key. In other words, there will no 'wrong' notes if the selected key suits the scale. In addition to the pentatonic notes, a timbral change in the sound could also be controlled simultaneously.

To create the sounds, granular synthesis was chosen as the synthesis method. Granular synthesis splits up an audio recording into tiny pieces (*grains*), typically 1 to 100ms in length. Each *grain* contains a section of the recording, which is then shaped by an amplitude envelope, and played repeatedly. Playing the single *grain* at different speeds is used to change the frequency and therewith the note played. By moving the *play-head* (scrolling) through the different *grains*, the temporal feeling of the recording can be stretched or scratched. Even freezing in the moment becomes possible (Roads 2004). This freezing effect is used in this implementation. When freezing, or looping the same *grain*, the overtone structure of the individual *grain* defines the resulting sound's timbre. Enabling the possibility to scroll through the audio file, respectively choosing which *grain* is looped, allows the user effectively control the timbre. Using this method, the resulting sound can be changed (just by changing the audio recording) very easily, providing a rich and complex outcome while keeping the control simple and consistent.

Visual feedback

The main aim of the active visual feedback is to give a visual cue for the initiation of the aural feedback. There were also thoughts towards aesthetic value when implementing the visual feedback. Bean contains an RGB LED that changes color when the instrument is moved. The light is only active when one or more of the capacitive touch pads are touched.

Mapping

A visualization of the mapping strategy of both the aural and visual feedback can be seen in Figure 7. The action to sound mapping was direct in nature. The pitch of Bean, taken from the orientation data, is mapped to the pitch of the notes of the pentatonic scale. That is, when Bean is tilted upward on the Y-axis (Figure 6) the notes rise in the pentatonic scale, and when Bean is tilted downwards on the Y-axis the notes fall. The timbre effect is controlled by the degree of roll in Bean. Meaning, when Bean is rotated around the X-axis, the granular synth skips between *grains,* which in turn gives the earlier mentioned change in timbral content. Normally, the Z-axis controls the panning of the resulting sound, however during the evaluation this was disabled due to technical issues with the sound system utilized in the Cope Foundation music therapy center.

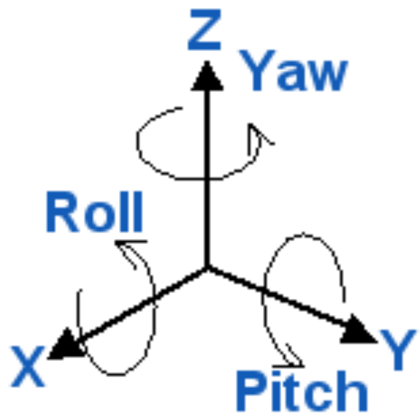

Figure 6 The interaction axes of Bean

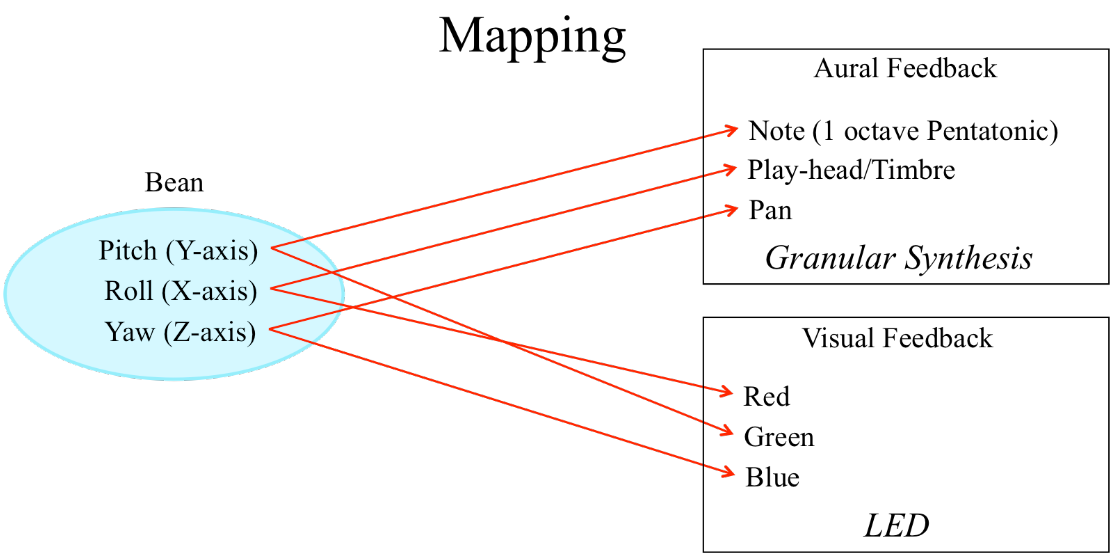

Figure 7 A visualization of the mapping strategy used in Bean for the evaluation

The control processing of the visual feedback is embedded in the tangible element of the system. The mapping of the visual feedback is arbitrary in nature, in that there is no direct action to colour mapping. That is, the values of the red, green and blue elements of the LED are scaled and mapped to pitch, roll and yaw respectively. For instance, when Bean is tilted up or down on the X-axis, the red element of the colour will become more or less apparent. This is true also for the Y and Z-axis and green and blue colours. Therefore, the colour is always gradually changing when bean is in motion around its axes. The colour is intended to add aesthetically to the visual appearance of Bean. It does not directly contribute information about the state of Bean[15] to the user aside from being consistent. That is, the colour and sound mapping are linked (Figure 7), so that a specific colour would consistently occur together with a specific variant of aural feedback.

5.3 Hardware

The hardware element of the prototype consists of a number of components (Figure 8), connected with a custom made PCB proto board. The placement of the electronics, the power switch, the programming port, the battery and the battery charging port, can also be seen here.

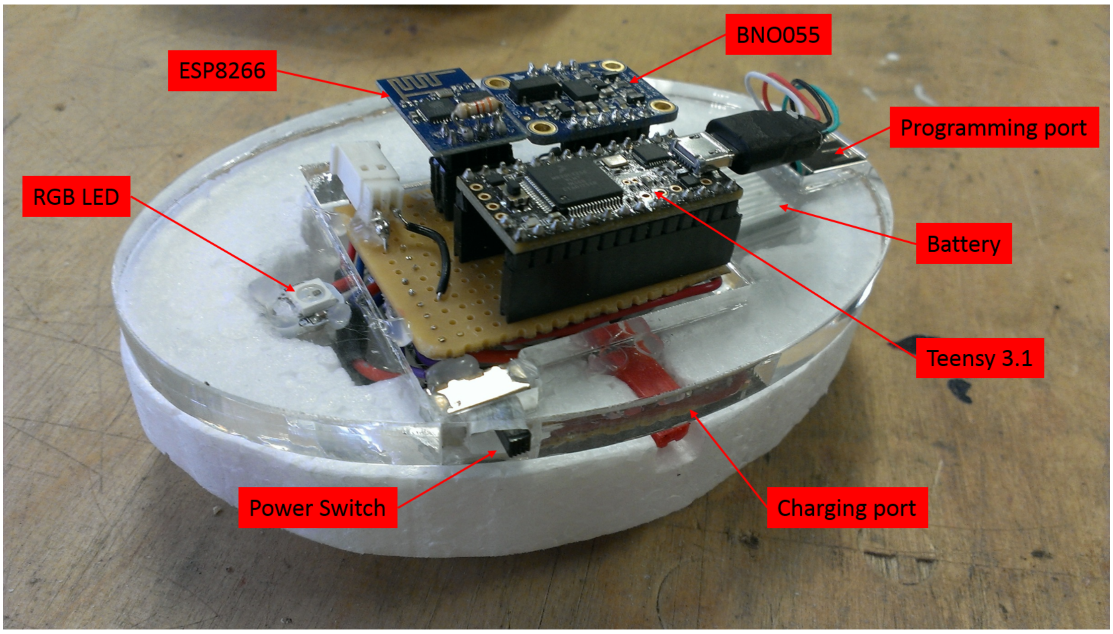

Figure 8 The hardware elements of Bean

Teensy 3.1

The ‘brain’ of Bean is the Teensy 3.1[16]. This is a small but powerful Arduino compatible microcontroller. This board connects and controls all the other hardware components. It also facilitates the capacitive touch and use of the RGB LED. There is

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[15] The colour change of the light is separated from the light state (on or off) when speaking of feedback to the user.

[16] https://www.pjrc.com/teensy/

a programming port installed in the acrylic plate to allow for firmware updating when the outer covers are on.

BNO055

The BNO055 is an inertial measurement unit (IMU) with an on board sensor fusion algorithm. This module contains an accelerometer, a gyroscope and a magnetometer, which provide 9 data streams. These data streams are then fused on-board for an accurate absolute orientation heading. This fusion algorithm can output various data streams, including three-axis absolute orientation in degrees and three axes of acceleration. The BNO055 module is connected to the Teensy, and transfers the orientation data through the I2C[17] protocol.

ESP8266

The ESP8266 is an Arduino compatible Wi-Fi System on Chip (SoC). This module is extremely cost effective and powerful for its very small size. The ESP8266, in this instance, functions as a User Datagram Protocol[18] (UDP) bridge. That is, it connects to the Wi-Fi network[19] and transfers data in a specific format from the Teensy to the Laptop. An Arduino sketch was created and loaded onto the ESP8266 for this purpose.

LED

An RGB LED connected to the Teensy provides visual feedback. This WS2812 LED[20] contains a control chip on-board, and consequently has a very small footprint. The LED chip and the Teensy communicate through SPI[21] protocol. Originally rated at 5volts, the LED has no trouble functioning with the 3.3volts the Teensy provides.

Latency testing

A latency test was carried out to evaluate the system in relation to real time interaction. This entailed recording an audio signal, which contained both the finger

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[17] https://www.pjrc.com/teensy/td_libs_Wire.html

[18] https://tools.ietf.org/html/rfc768

[19] Currently the Wi-Fi network is provided via a portable hotspot on a mobile phone.

[20] http://cdn.sparkfun.com/datasheets/Components/LED/WS2812.pdf

[21] https://www.pjrc.com/teensy/td_libs_SPI.html

hitting the capacitive pads and the resulting aural feedback. An image to clearly illustrate this can be seen in Figure 9. This audio file was recorded in Audacity, containing 20 touches of the capacitive pad and the subsequent 20 notes.

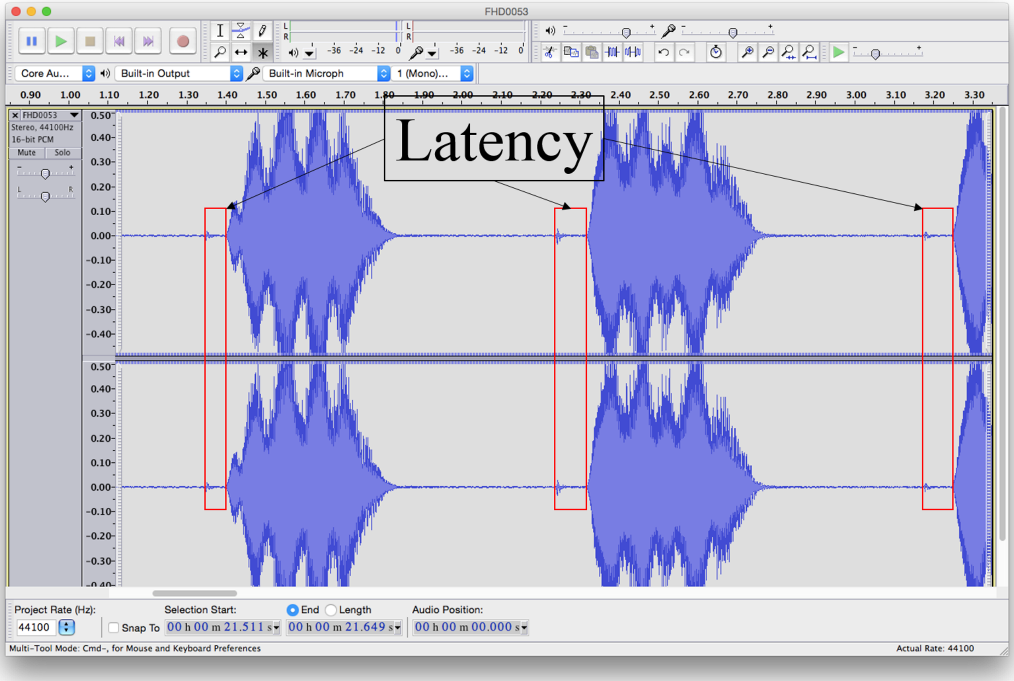

Figure 9 The audio file showing visible latency between interaction and sound

The latency was measured for each episode, and the mean of these 20 values was found. The minimum and maximum latency times were also noted. The results can be seen in Table 3 below.

Table 3 The values found during the latency test

Max	Min	Average
160ms	40ms	84.5ms

This result is relatively high. Wessel & Wright (2002) suggest that 10ms is an acceptable upper bound for latency of digital musical instruments, relating to virtuosic playing conditions. There is also a high variation between the minimum and maximum latency, which could result in audible inconsistency. Some of this latency could be immediately reduced by audio I/O optimization. This test used the standard audio buffer settings in Max/MSP of 512 samples. This produces an audio latency of 11.6ms in itself. A buffer of 128 samples for example, creates an audio latency of only 2.8ms, which is a saving of 8.8 milliseconds for a start. Optimization in other areas could also help reduce this latency further, and will be investigated in future work.

5.4 Software

The software elements of the system are instrumental in the functioning of Bean. They can be broken into two distinct groups. These are: firstly, the embedded software on the microcontrollers inside of the physical element of Bean, and secondly the software that facilitates the aural feedback on the laptop. These two groups will be further described in the following section. All of the software elements described below can be found on the accompanying USB flash drive (Software folder).

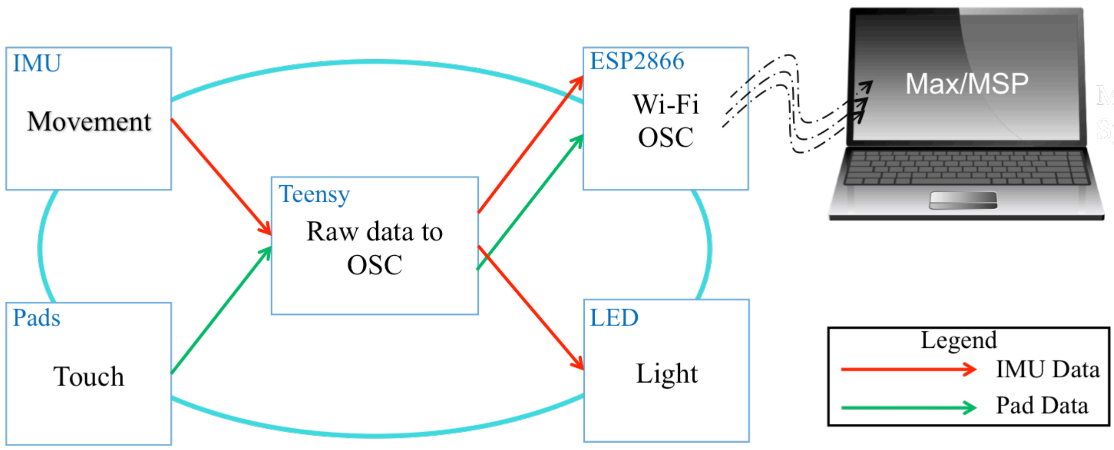

Figure 10 A visualization of the data flow in Bean

Embedded

The embedded software is comprised of two Arduino sketches, one on the Teensy 3.1 called Brain.ino, and one on the ESP8266 called Bridge.ino. The data flow in both of these sketches can be seen in Figure 10.

Brain.ino

This Arduino sketch enables the Teensy to function as the 'brain' of Bean. It was compiled by taking snippets from the various library code examples and some original code. The IMU data is gathered through the use of the Adafruit_BNO055 library[22]. The absolute orientation data and the acceleration data are accessed from the

[22] https://github.com/adafruit/Adafruit_BNO055

BNO055. These data are formatted to OSC with the 'address space' (Wright 2005) /data. The orientation data is routed directly to control the LED. The LED control is facilitated using the FastLED library[23]. Capacitive sensor data from the pads are also gathered and formatted to OSC. The combined OSC data is then packaged and sent to the ESP8266 using Serial Line Internet Protocol (SLIP) library[24].

Bridge.ino

The code in this sketch was adapted from code found on the ESP8266 Community Forum[25]. This Arduino sketch enables the ESP8266 to handle the wireless communication. The first routine this code facilitates is the specifying and joining of the Wi-Fi network. The bridge to the IP address of the laptop is then initiated. The SLIP OSC data is received from the Teensy. This data is then packaged for UDP transmission. The ESP8266 then transmits the data via UDP to the designated port on the laptop IP address.

Laptop

On the Laptop (a late 2008 MacBook Pro), a program created and running in Max/MSP, named *auralBean* facilitates the synthesis and control of the aural feedback.

Max/MSP

The *auralBean* patch[26] contains two sub-patches named *beanInput* and *rgrano*. These patches provide the following functions:

- Receipt of the OSC data through the specified UDP port
- Parsing and formatting of the OSC data into usable control data
- Connection of the relevant control signals to the Granular synth
- Output of the resulting aural feedback

[23] https://github.com/FastLED/FastLED/releases

[24] https://github.com/CNMAT/OSC/blob/master/SLIPEncodedSerial.h

[25] http://www.esp8266.com/viewtopic.php?f=29&t=4533&p=29149#p29149

[26] A program in Max/MSP is know as a patch, and a sub-patch is a program, which is embedded in another.

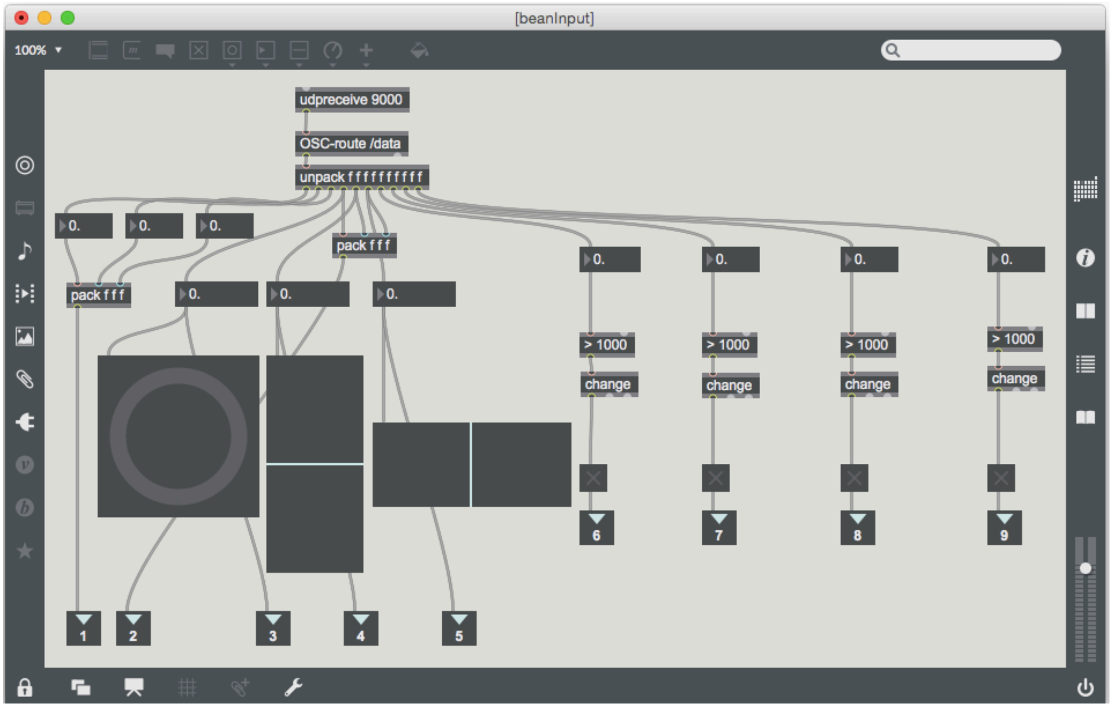

Figure 11 beanInput sketch, showing UDP receipt, parsing and formatting

As can be seen in Figure 11, the OSC data is received into *beanInput* from the UDP bridge on port 9000. The acceleration and orientation data are both packed into lists and sent to the first and second outputs respectively. The orientation data is also sent on as individual yaw, pitch and roll data to the next three corresponding outputs. The four capacitive touch pad data streams are also formatted here. In order to function as a switch, the capacitive data was set a threshold. When this threshold is crossed, a *true* message (1 in actuality) is sent to the output. However, if the value is under the threshold, a *false* (0 in actuality) message is sent to the output.

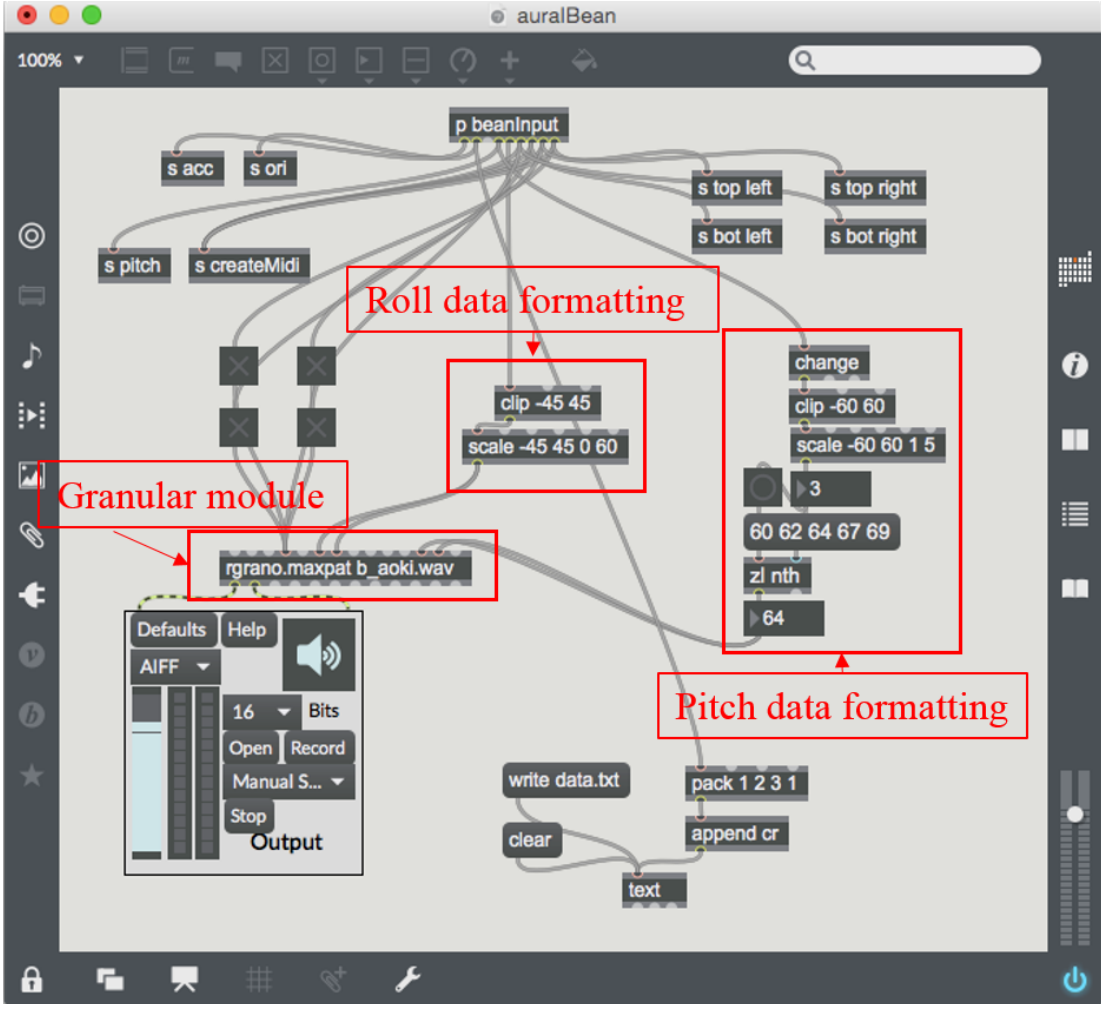

Figure 12 The layout of auralBean can be seen here

auralBean

The main function in *auralBean* besides *beanInput* is the formatting of the input data and use of that data to control the granular synthesis. A secondary function here is the further sending of the control data for other purposes, such as an initial GVF implementation, and a MIDI implementation. There is also the opportunity to write the orientation data to disk here. In Figure 12 we can see some of these functions highlighted.

The pitch data is limited to between -60 and 60 degrees, and then linearly scaled to between 1 and 5. That is, the data is scaled so that -60 or under would output 1 and 60 or over would output 5. The pitch data in theory should range from -90 to 90 degrees, however, in an attempt to ensure that all notes could be comfortably played, the data output is limited to within a smaller range of motion. The resulting number is then used to select a MIDI note number from a list, containing numbers corresponding to the pentatonic scale in the key of C. This number is then fed into the granular synthesis sub-patch.

The roll data is also limited, again in an attempt to ensure comfortable full control of the timbral element. The roll data output cutoff is below -45 and above 45. This is then linearly scaled to 0-60. This is an arbitrarily chosen scaling to give a subtle timbral change. This number is also then fed into the granular synthesis sub-patch.

The note-on data is directly fed to the granular synthesis sub-patch here also. All of the capacitive touch pad true/false data acts as a note-on trigger for the synthesis.

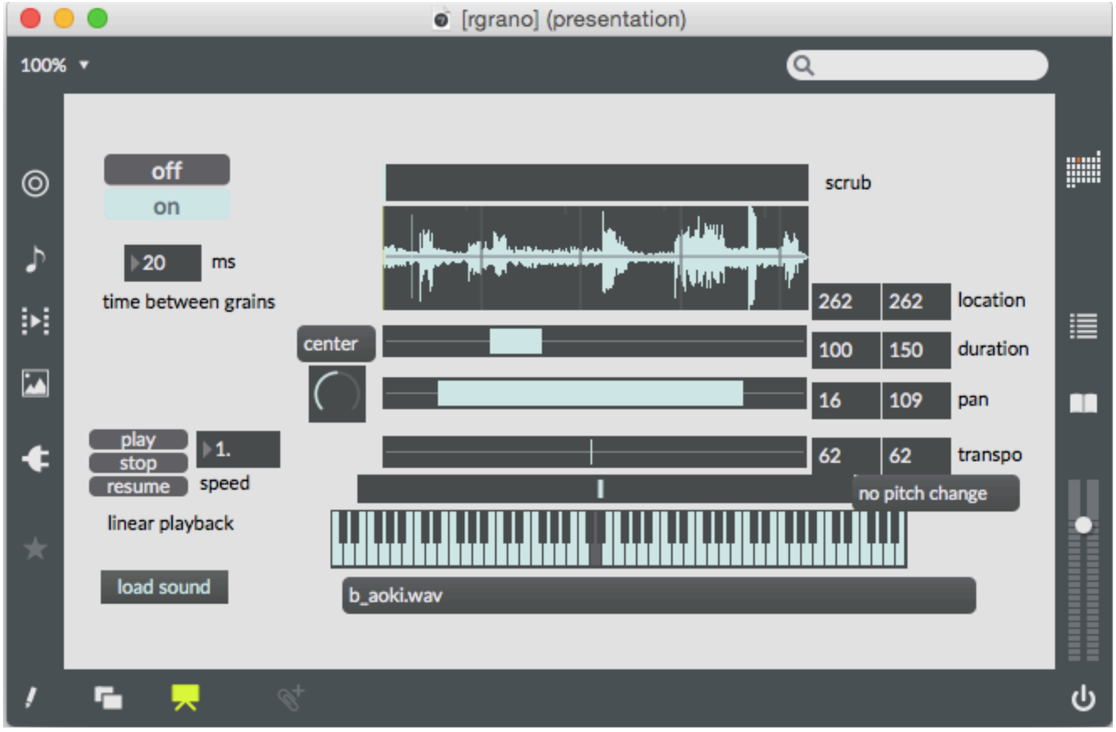

Figure 13 The granular synthesis sub-patch: rgrano

rgrano

The granular synthesis sub-patch used in Bean (Figure 13) is named *rgrano*. This abstraction is an example file from the Max/MSP tutorial on granular synthesis, and contains more than enough functionality for the current implementation. *rgrano,* among other things, facilitates scanning or *scrubbing* through the *grains,* and also changing the relative pitch of the *grains*. The source audio file used for the granular synthesis is b_aoki.wav. This file was chosen for aesthetic reasons, but as mentioned earlier, another audio file could be easily used totally changing the sonic characteristic of Bean. When the b_aoki.wav was played however, due to the nature of the granular synth, the pentatonic scale notes were in fact in the Key of G.

Initial GVF implementation

There was also an initial implementation of the Gesture Variation Follower using the earlier mentioned machine learning algorithms. This implementation allowed the switching between several audio files, and altering the playback speed/direction and volume via gesture. However, this implementation was not stable enough in time for the evaluation. There has been some further work done on this implementation since the evaluation, and it will therefore be described in more detail in the future work section.

6 Evaluation

This section will outline the steps taken to evaluate the prototype of Bean. The method section will describe the participative evaluation sessions. The participants themselves will be described, along with the procedure followed in each session.

6.1 Method

The evaluation consisted of three participatory sessions, which were conducted at the music therapy center in Cope Foundation[27]. The participant groups consisted of clients from Cope Foundation. They varied in age and complex needs. For a more detailed overview of the participant demographic see Table 4. The sessions were conducted over two days (7th and 8th December 2015). Sessions one and two were held on the first day and session three was held on the second day. Eoin Nash, a certified music therapist and manager of arts and creative therapies in Cope Foundation, facilitated the sessions. Permission to document with both audio and video was sought and granted for all participants. The evaluation was documented with a combination of audio and video recordings and note taking.

Table 4 Overview of the participants in the three evaluation sessions

Session No.	No. of participants	Age	Gender	Complex need	Plays music
1	13	12-15	8 male 5 female	Intellectual	3
2	7	18-21	2 male 5 female	Intellectual	3
3	2	Young adult	1male 1 female	Intellectual Physical	-

Session 1

The first session consisted of a class of thirteen students and two teachers from Scoil Bernadette. Scoil Bernadette is a primary school that caters for students between the ages of twelve and eighteen. The school is a part of Cope Foundation. This particular class was a music appreciation class. Three of the students had prior musical

[27] Cope foundation is a nonprofit organization based in Cork City, Ireland. http://www.cope-foundation.ie/

experience, i.e. played an instrument. The group was composed of young adolescents, aged between twelve and fifteen years of age, with mild intellectual disabilities. All participants were together in the room for the length of the session.

Session 2

The second session group consisted of seven students and one teacher from Doras. Doras is a post-school training service for people with a mild intellectual disability who are over the age of 16. This service is administered by Cope foundation. Three of the participants in this group played musical instruments. The group was composed of late adolescents with mild intellectual disabilities. All participants were in the room together for the length of the session.

Session 3

The third session group consisted of two clients from Cope foundation with severe to profound intellectual/physical complex needs. They are both young adults. Two personal helpers and a family member also participated. Due to the nature of their disabilities neither of the two participants played conventional musical instruments. All participants were in the room together for the length of the session.

Procedure

The sessions had a similar procedure, which is outlined here:

- A short introduction was given first by Eoin and the author
- Bean was shown to the group and they were shown basic usage instructions
- The participants were asked if they would like to try it
- Discussion followed with open ended questions
- Group playing/Jam session[28]

[28] Jam session, as used here refers to a group musical activity, which is unrehearsed and improvised.

6.2 Data analysis

This section will describe the analysis carried out on the data gathered during the evaluation. The evaluation data can be broken down in to three parts: 1) a participatory discussion; 2) an interview with a music therapist; 3) analysis of the interaction videos. These three sections can be related respectively to the *dialogue*, *feedback* and *indirect* observations, which define the information provided by *informants* (Figure 1). The outcome of this analysis is presented in the results section.

Participatory discussions

Dialogue from the first three participatory sessions has been transcribed from the audio and video sources. These data were then analyzed using open coding techniques to gather recurring or emergent themes in the participatory discussions.

IMTAP evaluation framework

The IMTAP system was used in two ways to provide a framework for investigation into the current state of Bean. Firstly, an interview with Eoin Nash, the music therapist who facilitated the assessment sessions in Cope foundation, was carried out. Secondly, the IMTAP was used to analyze some of the participants' interactions with Bean. In both instances, this framework was used as a contextual guide for the inquiry into the performance of the prototype Bean, in a direction relevant to music therapy practice.

Interview

Eoin Nash was interviewed in order to gain his professional *feedback* relating to Bean. A discussion with questions focusing on the domains described in IMTAP was conducted. Through this discussion the relevance and functionality of Bean was assessed. Potential uses and improvements were also discussed. Quotes relating Bean to the IMTAP domains were then selected, in order to summarize his thoughts on each.

Interaction analysis case studies

Video recordings of two of the participants from each session were chosen. This *indirect* observation information was then analyzed focusing on relevant IMTAP domains, in order to form a contextual image of their interaction with Bean. The Oral motor domain was omitted from this analysis, as it was judged not to be relevant to the usage of Bean. The information gathered here will be used to help with the further development of the interaction design of Bean.

7 Results

In this section the information gathered from the *informants* during the evaluation sessions will be presented. Firstly the *dialogue* content from participatory discussion sessions will be presented. After this the *feedback* from the interview with the therapist will be described, and finally the *indirect* observation information in the form of an interaction analysis will be presented.

7.1 Participatory discussions

The *dialogue* data from the three participatory discussion sessions were categorized into relating themes where possible, and visualized in a number of figures (see below). These figures serve the purpose of giving an easily understandable overview of the gathered information. The original transcriptions, and audio files can be found in the accompanying USB flash drive (Discussions folder).

Another element of this analysis contains a *word cloud* of each discussion. These can be found in the Appendix 2 and were created to give a supplementary overview of the three discussion sessions[29]. As mentioned in (McNaught & Lam 2010) there are limitations to this method of data visualization, however, it was deemed complementary in this instance, as the use of *word clouds* serve only the purpose of giving an immediate superficial impression of the information gathered during these discussions.

[29] Usage of the *word cloud* here relates to the method discussed in (McNaught & Lam 2010).

Aesthetics

There were three sub-categories found with comments relating to the Sound, Lights and general Design of Bean. They essentially each describe different aesthetic points of Bean and are presented in the following three figures (Figures 14, 15 and 16). The design category also includes thoughts on functionality.

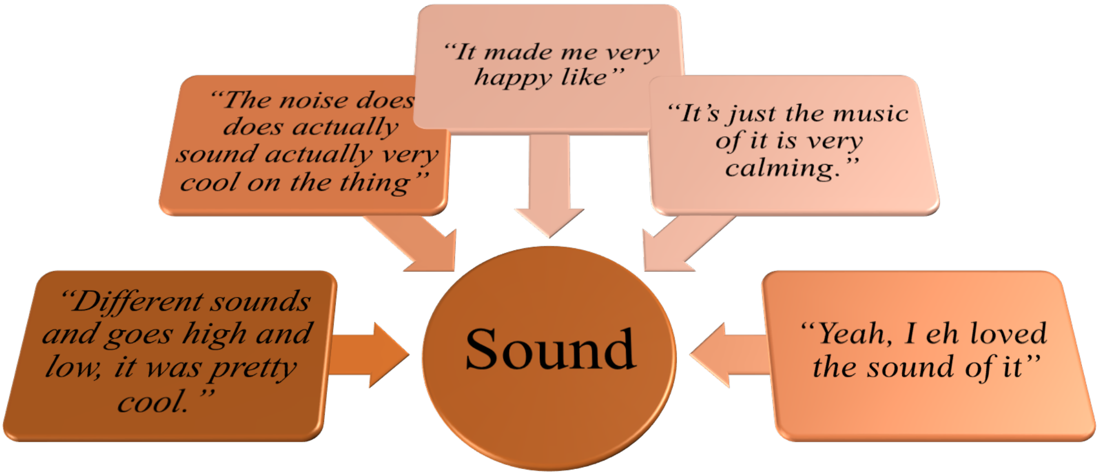

Figure 14 Comments relating to the aural feedback

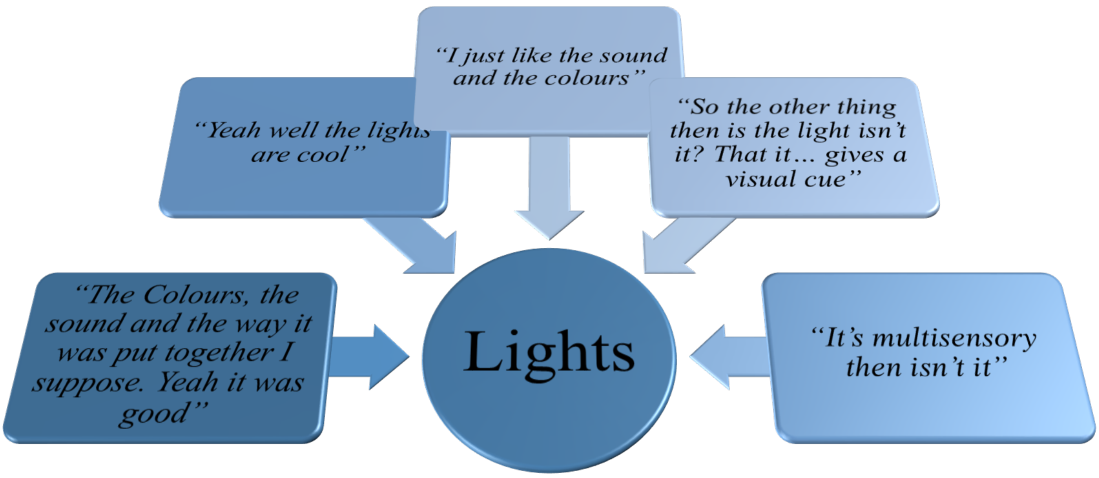

Figure 15 Comments relating to the visual feedback

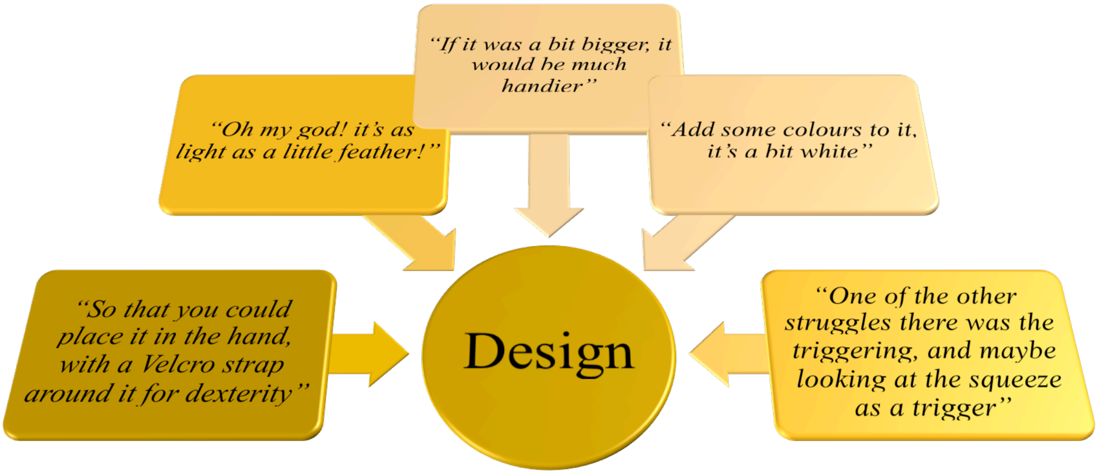

Figure 16 Comments relating to the overall design

Interaction

This next figure (Figure 17) shows the comments from the participants related to the interaction category.

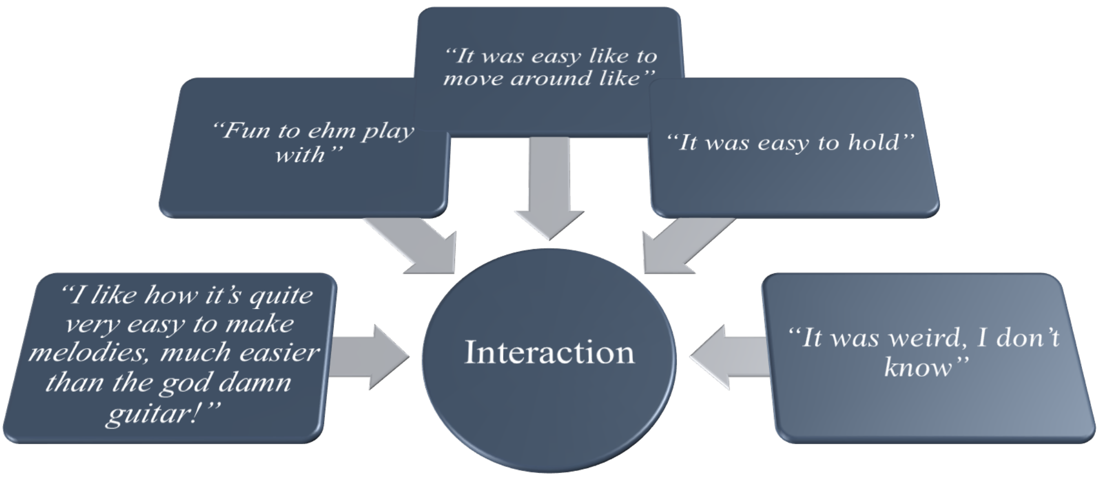

Figure 17 Several comments related to playing with Bean

Social

The figure below (Figure 18) shows some of the thoughts the participants shared about the use of Bean in a musically social setting. Below in Figure 19 an image illustrating the musically social scenario that arose in the jam in session 1.

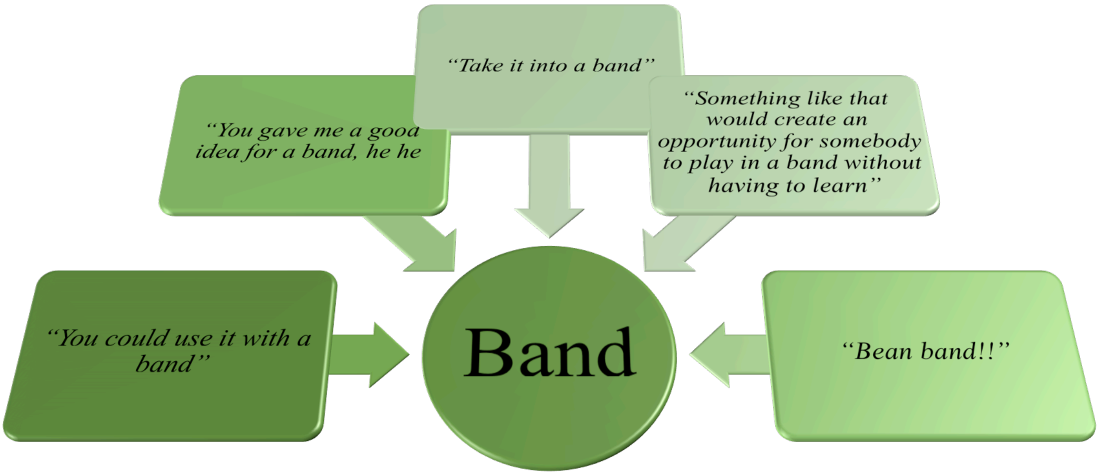

Figure 18 Comments relating to using Bean in a band

Figure 19 A participant playing with Bean in a group situation

Motivated movement

This category shows comments relating the use of Bean in a physically therapeutic music therapy scenario Figure 20.

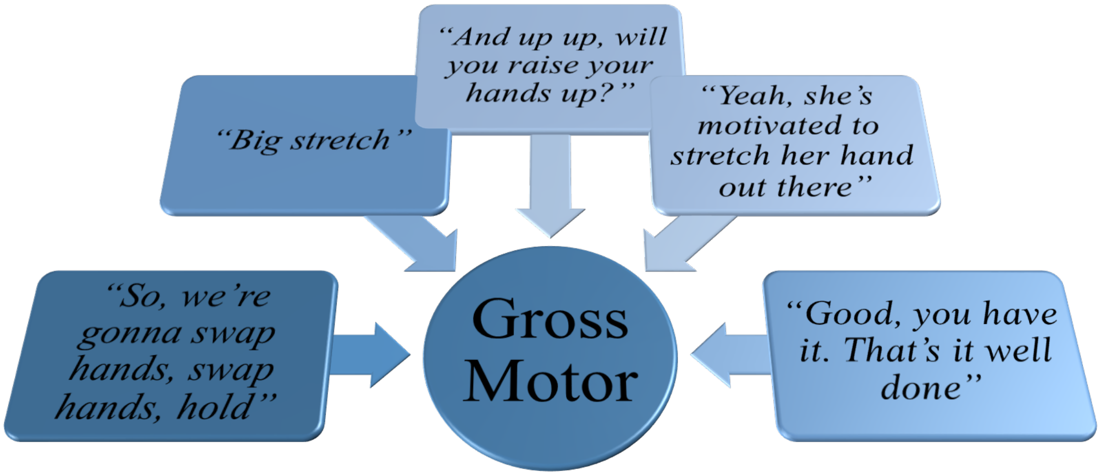

Figure 20 At the time of these comments the participants were training gross motor skills with Bean

Associations

There were also some interesting associations made between Bean and various things. These can be seen in Figure 21 below.

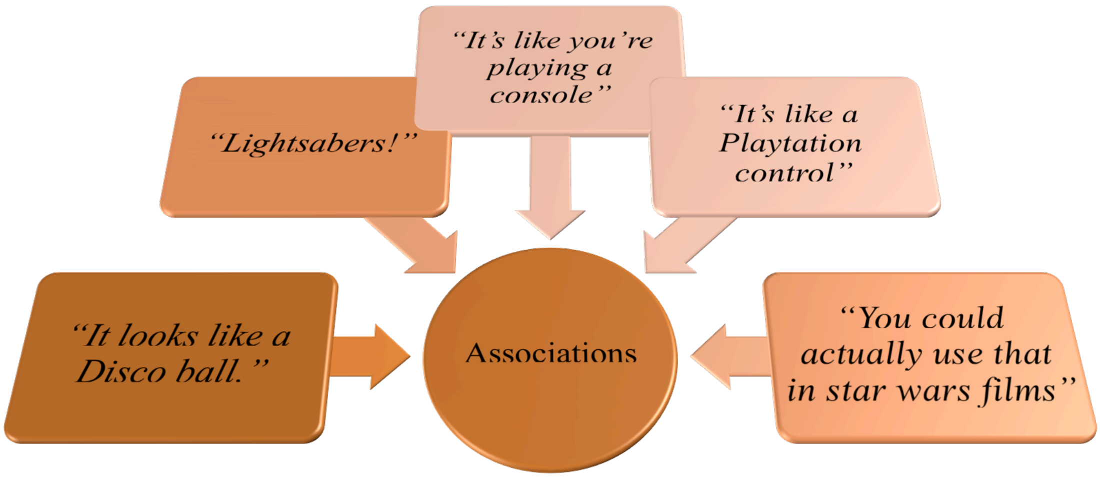

Figure 21 Associations ranging from a Disco ball to a Lightsaber

7.2 IMTAP evaluation

The *feedback* from the interview and the analysis of the *indirect* information gathered from the selected videos will be presented here. The IMTAP domain framework was used in the analysis of both.

Interview

The main points of the interview with Eoin Nash will be divided up into the domains suggested by the IMTAP and presented in Table 5 below. A full transcription of the interview, broken into these domains, can be found in PDF format along with the original audio files on the accompanying USB flash drive (Interview Folder). Unless pointed out, all quotes are from Eoin.

Table 5 Bean's relevance in relation to the IMTAP Domains

Domain	***Quotes***
Gross motor	*"So what there is in terms of Bean, is there is a motivating factor to explore gross motor movement… but you are also looking at you know potentially targeting torso movement as well"*
	"Well, it encourages and motivates the movement of the body to create sound and to engage"
Fine motor	*"So the bean now because of it's size, like, requires fine motor skills to hold it".*
	"The buttons that are on it", (Bean's capacitive sensors) *"will also create defined fine motor interventions"*
	"So it's controlled fine motor, but also grasping the Bean in itself".
Oral motor	*"Currently as it stands it is outside what Bean offers"*
	"You're not using oral motor skills for anything, you know"
Sensory	*"So what you have is an integration of senses in the actual activity itself. So it's integrating your auditory sense, touch, visual"*
	"What that does is helps people coordinate those senses just by actively engaging with it you know"
	"This gives you something tangible to hold like, yeah"
Receptive communication	*"Hmm, Yeah well obviously, you see I think this is more of an expressive tool than a receptive tool, do you know what I mean?"*
	"A therapist can use Bean, and the software program that enables different sounds, to explore different stimuli"
	"We know that people can receive stuff but not engage. So what this does so, is that it creates a stimuli that offers all those potentials"
	"So that allows then for diversity of sound, to be used through the use of software technology, making it accessible and affordable for a therapist to use"

Expressive communication	*"Bean provides the capacity for somebody to express themselves, in movement"*
	"It gives people a voice, a musical voice; where maybe they don't have an actual vocal voice you know… Where they don't have words"
Cognitive	*"Particularly in terms of a group context…Bean as an active instrument within that context, would facilitate direction following"*
	"Basic counting in a musical context. And positioning Bean in different areas for those times you know"
	"Well I mean, if you wanted to look at reading music. You know these are kind of potentials for development really like"
Emotional	*"Is Bean supporting the emotional expression of somebody? Like, you couldn't deny that it does"*
	"And I think you need to link that to the joy we saw on peoples faces that day Nick you know"
	"People were talking about it to each other and were excited about it".
Social	*"Everything, I mean it's everything in those. Turn taking, absolutely, over and back with live instruments, interacting with another Bean, stopping starting, direction following like we discussed earlier, following a conductor"*
	"It allows those who may be socially disadvantaged as a result of their disability, to engage socially within a musical context. This particular instrument, provides people with an opportunity to be included rather than excluded"
Musicality	*"So musicality crosses all of those domains, and is essentially the integration of those domains in itself, because it's creative, it's emotional, it's social it's all of those put together"*
	Nick: "For the test we did, the musical expression was fairly limited, I think wasn't it?" *Eoin: "Well it was, but remember we were saying, look lets find a couple of notes they could specifically do, and they were… But like, that's only a potential that can be built on"*

Interaction analysis

In this section the *indirect* information gained from the video analysis will be presented. The original video files can be found on the accompanying USB flash drive (Video folder). These case studies give a description of various interaction scenarios with Bean. The resulting IMTAP domain focused tables, can be found in Appendix 1. These tables were created to summarize contextually the participant's interactions. A short description of each case study will also be given here, highlighting some interesting points.

Case study 1:

Participant 1 (P1)[30] (Figure 22) from Session 1 (S1) is female, aged 12-15. She was one of the participants with prior musical background. She interacted with Bean with one hand, in fluid motions swirling up and down. The musical style consisted of sustained notes, and all of the possible notes were explored. She seemed to enjoy the experience of interacting musically with Bean, accompanied by Eoin on the piano. As a side note, the teacher informed us during the discussion:

"And just for your feedback, when M***(P1) sat down she said she felt like she was making music". (S1)

Figure 22 An interaction snapshot of participant 1 in session 1

See Appendix 1, Table 6, for the IMTAP domain analysis.

[30] P and S will be used as abbreviations for Participant and Session respectively. S also relates to which session the participant contributed to, and in which transcription the quote can be found. S1=Session 1-Discussion.pdf, S2=Session 2-Discussion.pdf and so on

Case study 2:

P2 (Figure 23) from S1 is male, aged 12-15. He did not have prior musical experience. He seemed very reserved, making very subtle hand movements at the start. However, when Eoin began to accompany him there was a reaction, granted very subtle, with more circular movements in tempo. Musically, there was very limited note choice and a long sustained style. Possibly the act of standing in front of the rest of the class had an influence on his reserved interactions. He also had one hand in his pocket throughout the interaction. The same level of enjoyment that was seen with P1 (S1) cannot be seen with P2 (S1) despite commenting in the discussion:

"It made me very happy like" (P2 S1)

Figure 23 An interaction snapshot of participant 2 in session 1

See Appendix 1, Table 7, for the IMTAP domain analysis.

Case study 3:

P3 (Figure 24) from S2 is male, aged 18-20. He did not have previous musical experience. He seemed happy to interact with Bean, however it was very distractedly. His attention seemed to be mostly on the others in the group while interacting. The time spent with Bean was also very short; he passed it on after just 25 seconds. Again, a sustained style of play was seen here, with all the notes explored. However, it is unclear if this was just a result of random arm movements, or in fact conscious exploration. As a side note, P3 seemed more fascinated with the lights than the aural feedback, in the discussion mentioning twice it looked like a light sabre from a star wars movie (S2).

Figure 24 Participant 3 interacting with Bean in session 2

See Appendix 1, Table 8, for the IMTAP domain analysis.

Case study 4:

P4 (Figure 25) from S2 is female, aged 18-20. There was two distinct phases in the interaction here. The first phase was exploratory in nature, where she carefully moved Bean and listened to the change in sound. The second phase was of a more social nature, where an impromptu jam started. P4 began moving and rhythmically tapping along with the rhythms from some of the other participants and Eoin on the piano. At this point it was clear to see that P4 was enjoying interacting with Bean in this social scenario.

Figure 25 Participant 4 during an impromptu jam session

See Appendix 1, Table 9, for the IMTAP domain analysis.

Case study 5:

P5 (Figure 26) from S3 is a young adult male. The outstretched arm pose we see in Figure 26 was one of the few times P5 moved with Bean. This happened after encouragement to move from the therapist, his helper and his mother. For the majority of the session he had his hands folded, and when he had Bean, it was held under one arm. This seemed to be a comfort pose for him. There was no clear sign of enjoyment during interaction with Bean.

Figure 26 Participant 5 stretching up after encouragement

See Appendix 1, Table 10, for the IMTAP domain analysis.

Case study 6:

P6 (Figure 27) from S3 is a young adult female. It was not possible for her to grip Bean. Therefore her personal helper assisted her throughout the interaction. It appeared that she was very happy to interact with bean, using her thumb and knuckles. Unfortunately in this video it seemed that while the helper was holding Bean, she also triggered the sounds, which could have led to confusion. However, there is clear evidence during the session that P6 enjoyed the experience and wanted to try it again:

Eoin: "Ok, that's great. I think it just gives us a good sense of the potential for it like".

All: "Clapping"

P6: (Vocalizing) "Again"!

Nick: "Thanks a million".

P6: (Vocalizing) "Again"!

Eoin: "Again"?

Nick: "Again? Yeah, of course"!

(S3)

Figure 27 Participant 6 being assisted by her personal helper during interaction

See Appendix 1, Table 11, for the IMTAP domain analysis.

8 Discussion

The evaluation process was challenging. When working with those with complex needs, the traditional usability testing data collection methods of questionnaires and surveys might not always be possible, as was the case in the evaluation presented here. This also means that quantitative data analysis, and empirical data, was not a feasible option. Therefore, a participatory framework for data collection, and analysis was used to structure the gathered data into a comprehensible format. Ideally the evaluation of Bean would entail a longitudinal assessment carried out by a certified therapist. This evaluation could track the effectiveness of Bean with same clients recurrently over a prolonged time period. This is also a goal looking towards future developments. The IMTAP was designed as a longitudinal tool, and as such, it could be seen as contradictory to the method described in this thesis. Due to time constraints, the current evaluation was in essence a discrete snapshot, to gauge Bean's relevance and current functionality. However, the domains used in the IMTAP provide a vital contextual relevance to common practice in music therapy and is widely used by music therapists (Hahna et al. 2012). Thus, analysis with the IMTAP, of participatory input and professional opinion from *informants* proves valid as a valuable insight into the contextual relevance, and usability of Bean.

Multimodal Feedback / Aesthetics

Eoin referred to the multimodal functionality of Bean positively, relating to a therapeutic intervention that would target the Sensory Domain, in the following comments:

"So what you have is an integration of senses in the actual activity itself. So it's integrating your auditory sense, touch, visual"
"What that does is helps people coordinate those senses just by actively engaging with it you know" (Table 5)

Referring to the individual modalities, as is seen in Figure 14, the aural feedback received very positive remarks such as: "*The noise does, does actually sound actually very cool on the thing*" (P4 S2) and *"Yeah, I eh loved the sound of it"* (P4 S1). Despite being, as Eoin put it: *"only a potential that can be built on"* (Table 5). The aesthetic element of the visual feedback also seemed well received, judging by some of the remarks in Figure 15 such as *"Yeah well the lights are cool"* (P4 S2) and *"I just like the sound and the colours"* (P5 S2).

There was a more mixed reaction in relation to the design (Figure 16). The Styrofoam cover was, understandably, not to everyone's taste. The material, while functional, is not the most aesthetically pleasing. However, for the evaluation it performed its main function of protection well, and the spare parts that were created were luckily not needed during testing. In future iterations a semi-transparent material will be used, thus eliminating the over 'whiteness' of the current design. The eventual plan is that the whole of Bean should in fact glow with the current selected colour. As mentioned earlier the aesthetics of the design would ideally generate interest in Bean, contributing to the motivation to use it, and a good sign of this interest could be the associations the participants made with Bean, such as *"You could actually use that in star wars movies", "Lightsabers!"* (P3 S2) *and "It's like you're playing a console"* (P4 S2). These show at least that Bean motivated the participants' imagination. Overall, the visual and aural content received sufficient positive interest, along with these imaginative associations, to conceivably contribute in creating a motivation to use Bean.

Interaction

The participatory sessions returned mostly positive participation levels, in that only 2 of the 22 participants (one from session 1 and one from session 2) would not touch or interact with Bean, and of the 20 that participated the majority explicitly expressed enjoyment during the interaction. Eoin also highlighted this point in the emotional domain section of the IMTAP interview:

"Is Bean supporting the emotional expression of somebody? Like, you couldn't deny that it does"

"And I think you need to link that to the joy we saw on people's faces that day Nick you know" (Table 5)

One of the other comments in Figure 17 mentions that Bean was: *"Fun to ehm play with"* (P3 S2). This fun element can also be seen in this participant's case study (3) video (Figure 24). In case studies 1 (Figure 22) and 4 (Figure 25) the impression of having fun is even more evident. While harder to judge by visual means, in case study

6 (Figure 27), it could be posited that P6 (S3) also experienced fun during interaction with Bean, which led to the vocalized exchange where P6 (S3) wanted to interact with Bean again. Interestingly, the analysis of case study 2 (Figure 23) showed no visible signs of enjoyment, but during the participatory discussion the same participant commented: *"It made me very happy like"* (P2 S1). The remaining case study (case study 5) was inconclusive in relation to observing any signs of fun. Other comments, which could be related to higher or lower levels of enjoyment include: *"I really liked it"* (P6 S2) and *"It was weird, I don't know"* (P6 S1).

The goal relating to simple and intuitive use, which directly relates to the third principal of Inclusive Design, comes to mind when looking at the comments in Figure 17. Three of the five comments mention that Bean was easy to use. This seemed to be the general consensus across the first two sessions. The participants did not have a problem in understanding how to interact with Bean and explained with comments such as: *"it makes different sounds and goes high and low"* (P1 S2) and *"It was easy to move around like"* (P4 S1).

O'Malley et al. (2004) posit that tangible interaction encourages discovery and participation, and it could be argued that both elements were seen during the evaluation. When looking at interaction alone, the fact that 81% of the participants were willing to interact with Bean, suggests a high level of participation. However, it is unclear if Bean is the sole reason for this high percentage of participation. One thing is clear; the majority of participants were very willing to contribute to the future development of Bean with both *indirect* and *dialogue* input. As regards the encouragement of discovery, all the participants who interacted with Bean were essentially exploring musically to greater or lesser extent. In the case studies, this exploration and resultant discovery can be seen in varying levels. For instance, in case study 1 (Figure 22) the participant listened intensely, while making swirling up and down movements. Exploring all the available notes. Case study 2 (Figure 23), shows a much more subtle level of exploration. The participant is barely moving Bean, and rarely changing notes. Whether or not this exploration and subsequent discovery is a product of the tangibility element in Bean cannot be stated with certainty. However, it can be suggested that both elements were present during interaction with Bean.

In order to explore and discover, one must be engaged on some level. Moreover, Bean requires *engagement*[31] for any meaningful interaction with it. This idea of engagement relates back the earlier mentioned *tangible-enactive space.* This requirement of *engagement* would tend to suggest that Bean holds traits from the enactive approach. The other axis in the *tangible-enactive space* is *timeliness*. The results gained from the latency test for Bean are not ideal, indeed it is far from the suggested 10ms in (Wessel & Wright 2002). It is clear that more work must be done to improve this issue, and reduce the latency as much as possible. However, if the focus in creating Bean were on virtuosic playing, this latency issue would be a much greater problem. Facilitating virtuosic playing though was never an aim during the design and construction of Bean. That said, Bean is still a quite timely TUI, in comparison to for instance, the slot machine mentioned in (O'Modhrain 2007). The method of interaction with this slot machine (Perlman 1976) contains separate discreet actions, and a delayed combined execution by the computer of these actions afterwards, this is described as *untimely* because of the lack of real-time processing. Therefore it can also be posited that according to the logic of the *tangible-enactive space,* Bean is a tangible interface, which enables enactive interaction.

Motivated movement

In session 3 (participants with complex physical needs) where case study 5 (Figure 26) and 6 (Figure 27) took place, there was a more defined focus. This focus was more on the physical interaction aspects with Bean, which are referred to as gross and fine motor skills in IMTAP. Figure 20 illustrates some comments from these two scenarios, where Bean was used to provide the motivation to move. Eoin had this to say about the aspect in the interview:

> *"So what there is in terms of Bean, is there is a motivating factor to explore gross motor movement… but you are also looking at you know potentially targeting torso movement as well".* (*Table 5*)

---

[31] "*It must be remembered that the concept 'engaging' not only considers the attention span of the user, and how occupied they are with the interface, but also by how much the interface needs the involvement of the user to function"* (O'Modhrain 2007).

This would imply in Eoin's opinion, Bean would be a relevant tool to use relating gross and fine motor skill interventions in music therapy. However, judging Bean's success in generating motivation returns mixed results. It is clear from observations on the day of the evaluation, and in the transcripts and video, that the participant from case study 6 was motivated to interact with Bean. A snippet from the third session discussion illustrates this further:

(Eoin attempts to use Bean with P6 to motivate her to move)

Eoin: *"But if I was to ask you to use your left hand ok, to stretch out?"*

(P6 makes visible movement of the left hand towards Bean)

P5's Helper: *"Wow, well done."*

Eoin: *"You know… Excellent, well done! - So if you look… look straight at it, will you move your head to look straight at it? Well done."*

(S3)

However, as mentioned earlier, self-controlled fine motor interaction with Bean was impossible for P6 (S3). Bean in its current design does not optimally provide the flexibility in use, suggested by the second Inclusive design principal, for a full interaction potential for people with fine motor complex needs. Based on some discussion and comments similar to this:

"One of the other struggles there was the triggering, and maybe looking at the squeeze as a trigger" (Eoin S3).

A future iteration will investigate improving this flexibility through the squeeze interaction mode. It seems to be a less fine motoric intensive possibility. In the future work section, this topic will be mentioned again.

P5 (S3) from case study 5 gave a different impression regarding motivation to move. He kept Bean under his folded arms for most of the interaction. Indeed, Figure 26 shows one of the very few times he moved with Bean, stretching his arm up. This was also after heavy encouragement from his mother, helper and Eoin. It appeared that Bean was in fact close to being redundant in this instance. One of the only positives in fact was that P5 practiced swapping something (It was Bean, but it could just as well have been a ball) from one hand to the other. In essence, there seemed to be little or no, motivating factors from Bean in P5's actions.

Musicking

As mentioned earlier, the literature suggests that tangible interaction tends to support social interaction (Hornecker & Buur 2006). In case study 4 the participant is very much participating socially with the group. Bean in this instance can be seen to facilitate this musically social interaction of jamming, or *musicking*. The sense of empowerment described in (Cappelen & Andersson 2014) is perhaps too nuanced to find evedent in Bean after the current evaluation. However, specifically musical empowerment would be central in interaction with Bean, and as seen in the following quote, there are hints towards that the facilitation of this:

> *"And just for your feedback, when M**** (P1) *sat down she said she felt like she was making music"*. (Teacher S1)

A socially musical aspect was apparent a number of times during the first two discussion sessions. From the point of view of *musicking,* a band is essentially a social construct. As can be seen in Figure 18, using Bean in a band is mentioned multiple times. Here is a particularly apt comment:

> *"Something like that would create an opportunity for somebody to play in a band without having to learn"* (Eoin S2).

Indeed Eoin's opinion during the IMTAP interview, relating to the social domain is quite clear also:

> *"It allows those who may be socially disadvantaged as a result of their disability, to engage socially within a musical context. This particular instrument, provides people with an opportunity to be included rather than excluded".* (*Table 5*)

Instances of group playing, including Bean, could be seen during the jam sessions in the first and second participatory sessions. Figure 19 shows one such instance in the first session, where a participant is playing Bean while others in the group are playing percussion instruments and Eoin is playing piano. While this cannot be directly called a band, the scenario shares similarities with how many bands start, as a group of people jamming together.

The impromptu jam mentioned in case study 4 (Figure 25) can be described as an instance of *musicking.* The interaction evolved quickly from a solo exploratory style to a very socially communicative musical instance. This is the essence of how *musicking* would be defined for the purpose of this thesis, and it cannot be denied that Bean played a part in facilitating this *musicking*.

9 Conclusion

On the whole Bean performed well in the evaluation. It was found relevant as an assistive music technology in a music therapy setting. Simple and intuitive use allowed the majority of participants to enjoy interacting with Bean. The aesthetics of the prototype was well received despite a construction material, which did not suit all participants' tastes. The feeling of music making was facilitated by Bean and during the evaluation there was observed several musically social episodes of *musicking*, which were also in part facilitated by Bean. The motivation to move was also explored, where bean showed potential for use with clients who have complex physical needs. This is by no means a finished product. However, it was suggested, through professional *feedback* that Bean would be a welcome addition to the music therapist's toolkit, meriting further work to optimize the design. In the end it is up to the therapist to choose the suitable time to use Bean, if at all, but with a relevant and flexible design, simple and intuitive use and an enactive focal point, it will offer an alternative to current prevalent assistive music technologies.

10 Future work

There has been continued work on Bean since the evaluation. The main points of this further development center around two points:

- The development of an easy to use sound control interface using MIDI.
- The implementation of gesture variation recognition

MIDI Control

A patch in Max/MSP has been created, after discussion with Eoin, in order to provide an easy to use control interface for changing the musical interaction abilities with Bean. This concerns directly an implementation of MIDI (Figure 28), where the amount of available notes can be changed, relative to the pitch movement of Bean. Also, the musical scale that these notes will adhere to can be chosen, for instance, Major or Minor. The key Bean will play in can also be changed here.

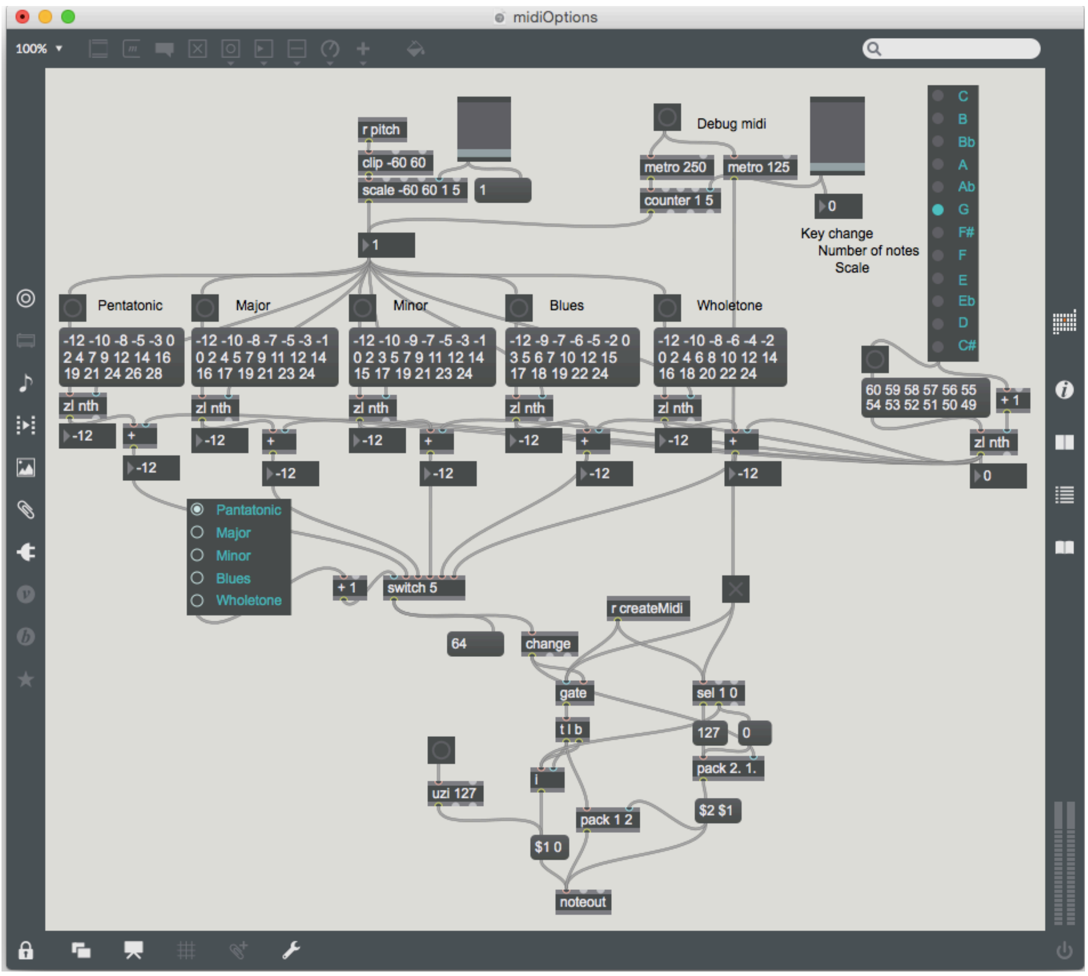

Figure 28 midiOptions facilitates various musical interaction possibilities with Bean, for those with reduced movement possibilities

The rationale behind this is, is to enable a greater amount of musical interaction when the client might have a restricted amount of physical interaction with Bean. This was discussed during the third participatory session, and would mainly be aimed at benefitting clients with complex physical needs. In fact, both the participants from case studies 5 and 6 would possibly benefit from this implementation. It also adds more general flexibility to the musical interaction possibilities. The implementation must be easy to use, so that the therapist can control these parameters intuitively. The control panel of the above patch can be seen in Figure 29.

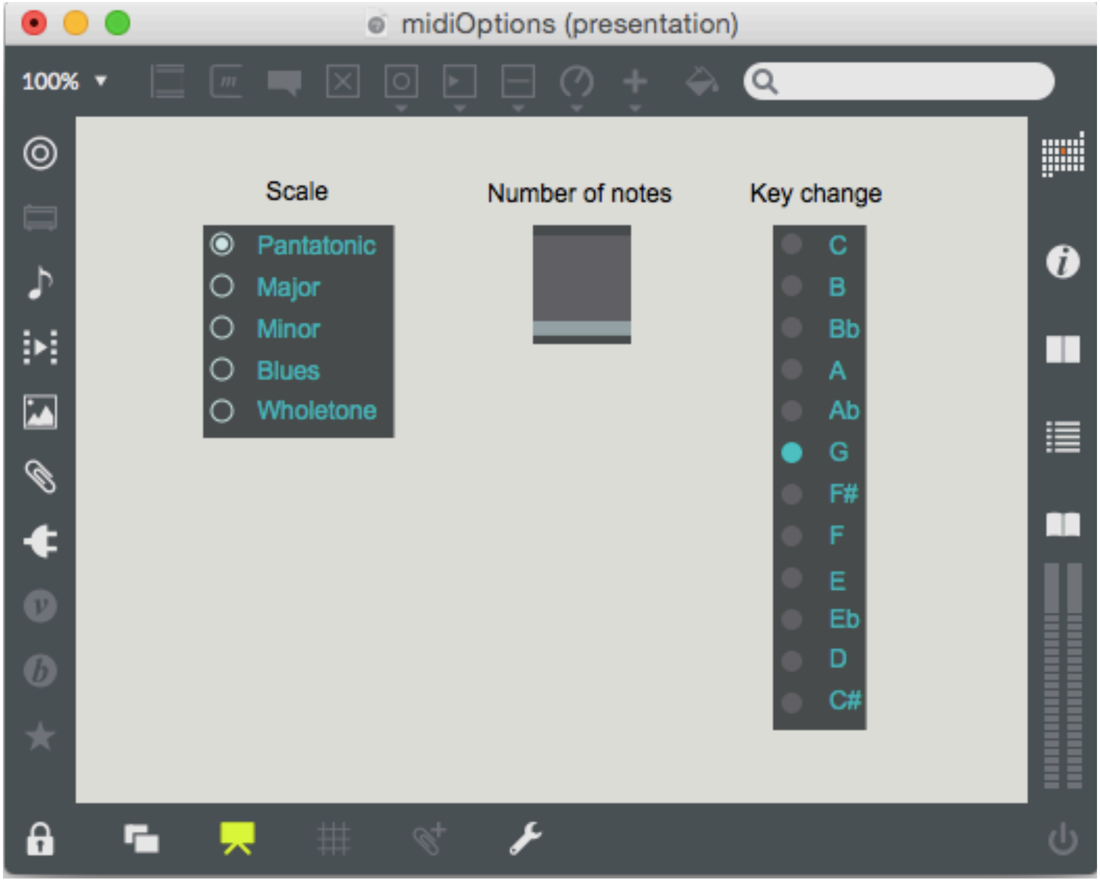

Figure 29 Musical interaction possibility control panel

GVF

The rationale behind the implementation of ML in Bean, is to explore the cutting edge mapping possibilities afforded by having the dynamic added layer of adaptive processing facilitated by the Gesture Variation Follower. While still in the experimental stage of development, the implementation with Bean shows promise. Below an image of the current implementation can be seen (Figure 30).

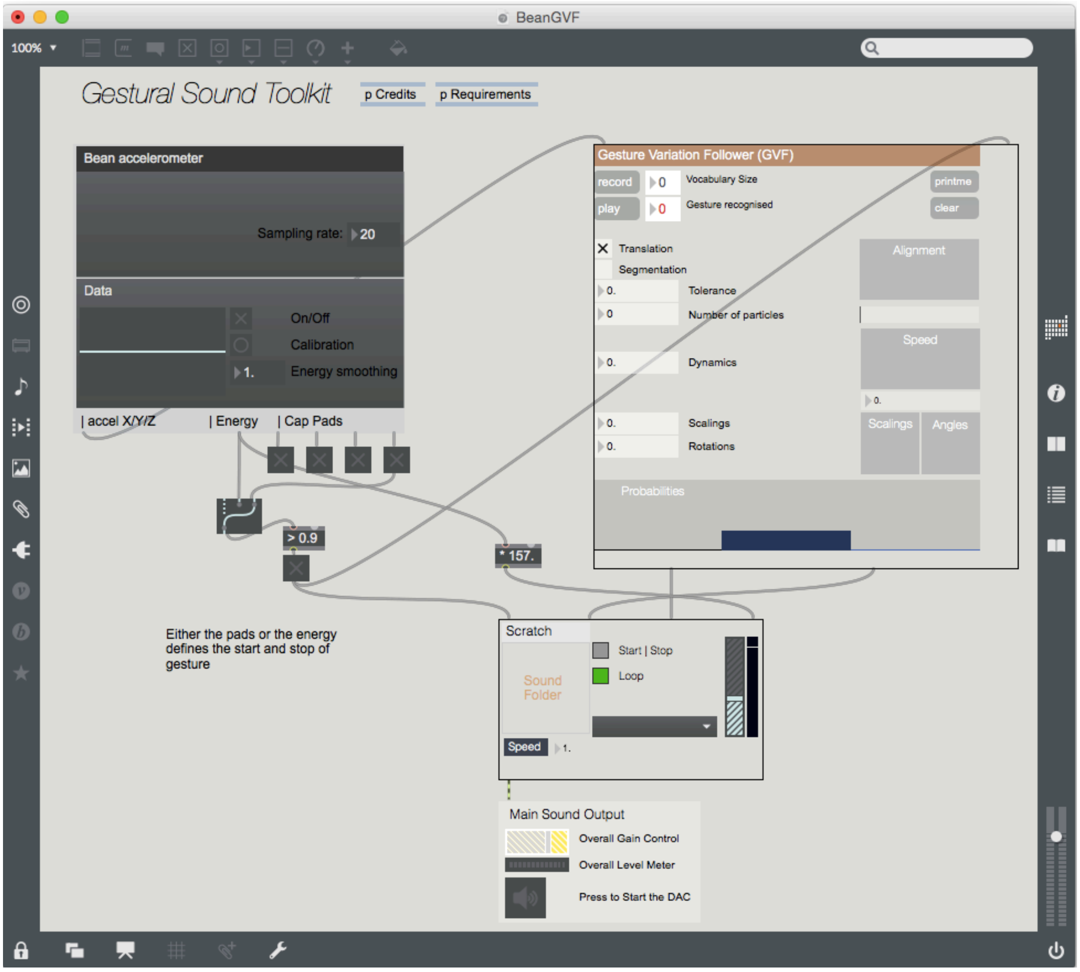

Figure 30 The current state of the GVF implementation

The ML algorithm (Particle filtering (Caramiaux 2012)) can estimate the gesture from the accelerometer data sent from Bean. It also continuously tracks and outputs values for the alignment, scaling, speed and angle of the estimated gesture. An index number is given to each number, and the index of the most probable estimated gesture is also output. The energy of the accelerometer is also calculated. In the implementation above, the GVF is trained by pressing one of the capacitive pads while making a gesture, and during play the energy amount from the accelerometer, initiates the gesture recognition and variation following. Currently only the speed and audio sample are determined by the GVF. The volume is directly tied to the energy output from the accelerometer. Although the implementation of the GVF is not optimal, the potential of this method is apparent and work on it will continue.

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12 Appendix

12.1 Appendix 1 – *Indirect* observation information from video

Case study 1, session 1:

Table 6 IMTAP analysis of case study 1. Interactions are observed on video and listed according to the IMTAP domains. Participant 1 is a female, 12-15 years, who has mild intellectual disabilities.

Domains	Interaction
Gross motor	One handed interaction involving shoulders Standing position
Fine motor	One finger constantly placed on the capacitive sensor
Sensory	Intermittent eye contact with Bean Tactile
Receptive communication	Seems to be listening intensely
Expressive communication	Free in movement Swirling up/down movements
Emotional	Smiling Enjoyment is clear
Social	Open Seems comfortable interacting with Bean and the piano
Musicality	Continuous note playing Explored all the possible notes

Case study 2, session 1:

Table 7 IMTAP analysis of case study 2. Interactions are observed on video and listed according to the IMTAP domains. Participant 2 is a male, 12-15 years, who has mild intellectual disabilities.

Domains	Interaction
Gross motor	One handed interaction Standing position
Fine motor	One finger constantly placed on the capacitive sensor
Sensory	Constant eye contact with Bean Tactile
Receptive communication	Possibly listening intensely (hard to discern)
Expressive communication	Constricted in movement Slight up/down movements (exaggerated with piano backing)
Emotional	Neutral Hard to determine any emotion
Social	Closed Seems uncomfortable interacting with Bean (in front of others)
Musicality	Continuous note playing Very limited note choice (because of subtle movement)

Case study 3, session 2:

Table 8. IMTAP analysis of case study 3. Interactions are observed on video and listed according to the IMTAP domains. Participant 3 is a male, 18-20 years, who has mild intellectual disabilities.

Domains	Interaction
Gross motor	One handed interaction including upper torso Sitting position
Fine motor	Two fingers and thumb constantly placed on the capacitive sensors
Sensory	No eye contact with Bean (seems distracted by the group) Tactile
Receptive communication	Possibly listening (if so only partially)
Expressive communication	Relaxed in movement (one hand in pocket) Circular and up/down movements (rigid arm)
Emotional	Smiling Shows signs of enjoyment
Social	Open (slight embracement possibly) More concentrated on the group than on Bean
Musicality	Continuous note playing Explored all the available notes

Case study 4, session 2:

Table 9. IMTAP analysis of case study 4. Interactions are observed on video and listed according to the IMTAP domains. Participant 4 is a female, 18-20 years, who has mild intellectual disabilities.

Domains	Interaction
Gross motor	One and two handed interaction (upper torso/shoulders) Sitting position
Fine motor	Two and four finger interaction Rhythmic tapping on the capacitive sensors
Sensory	Intermittent eye contact with Bean Tactile
Receptive communication	listening (when not talking to the group, mostly at the start)
Expressive communication	Concentrated exploratory movement at the start Two handed twisting and swirling
Emotional	Smiling Shows signs of joy during interaction
Social	Very open Positive reaction to spontaneous jam
Musicality	Firstly continuous notes, exploring all the available notes Later, during a jam with the others, rhythmical tapping

Case study 5, session 3:

Table 10. IMTAP analysis of case study 5. Interactions are observed on video and listed according to the IMTAP domains. Participant 5 is a young adult male, who has complex physical and/or intellectual needs.

Domains	Interaction
Gross motor	Mostly arms folded, outstretched arms at one point Passed bean from one hand to the other
Fine motor	Grabbed Bean Multiple fingers on Bean intermittently
Sensory	No eye contact with Bean Tactile
Receptive communication	Possibly listening (very hard to discern)
Expressive communication	Arms outstretched after encouragement Mostly folded hands (seems to be a comfort posture)
Emotional	Smiling after interaction and encouragement
Social	Social contact through smiles (despite limited ability)
Musicality	One note Intermittently played

Case study 6, session 3:

Table 11. IMTAP analysis of case study 6. Interactions are observed on video and listed according to the IMTAP domains. Participant 6 is a young adult female, who has complex physical and/or intellectual needs.

Domains	Interaction
Gross motor	One handed interaction Head movement to look at Bean
Fine motor	Limited dexterity Thumb contact (while the helper held Bean)
Sensory	Intermittent eye contact (physical effort needed for this) Tactile (possibly of greater impact here)
Receptive communication	Possibly listening (very hard to discern)
Expressive communication	Right arm/hand intentionally placed towards Bean Excited vocalization
Emotional	Smiling during interaction
Social	Social contact through smiles and vocalization (despite limited ability)
Musicality	One or two notes Intermittently played

12.2 Appendix 2 – Word clouds

Figure 31. Word cloud composed of the discussion in session 1. Session 1 was composed of young adolescent participants, with mild intellectual disabilities, two teachers, a trained music therapist and the author. The words that appear larger occurred more often in the discussion.

Figure 32. Word cloud composed of the discussion in session 2. Session 2 was composed of late adolescent participants, with mild intellectual disabilities, a teacher, a trained music therapist and the author. The words that appear larger occurred more often in the discussion.

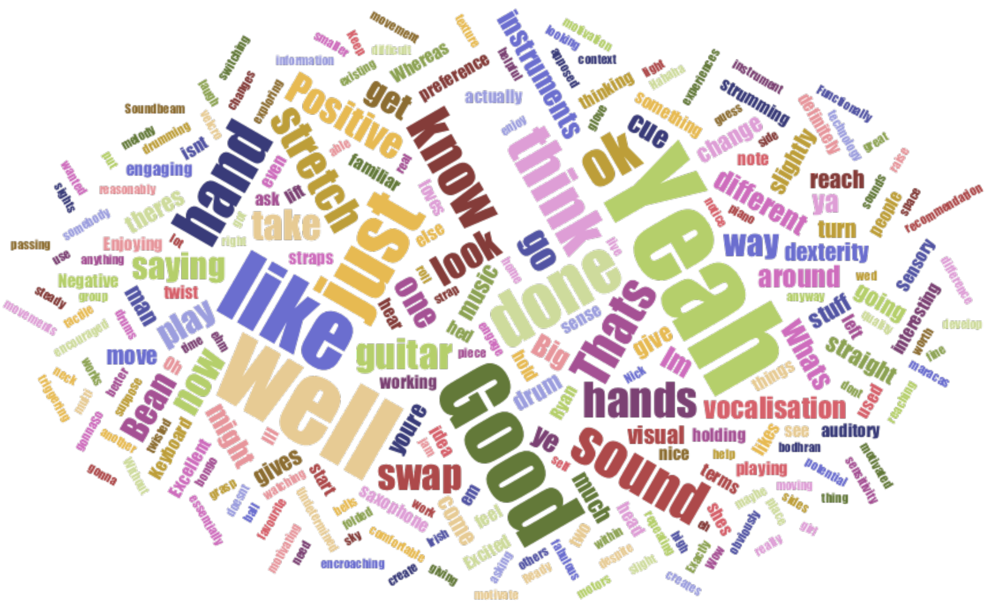

Figure 33. Word cloud composed of the discussion in session 3. Session 3 was composed of participants, with complex physical and/or intellectual disabilities, their parents, helpers, a trained music therapist and the author. The words that appear larger occurred more often in the discussion.