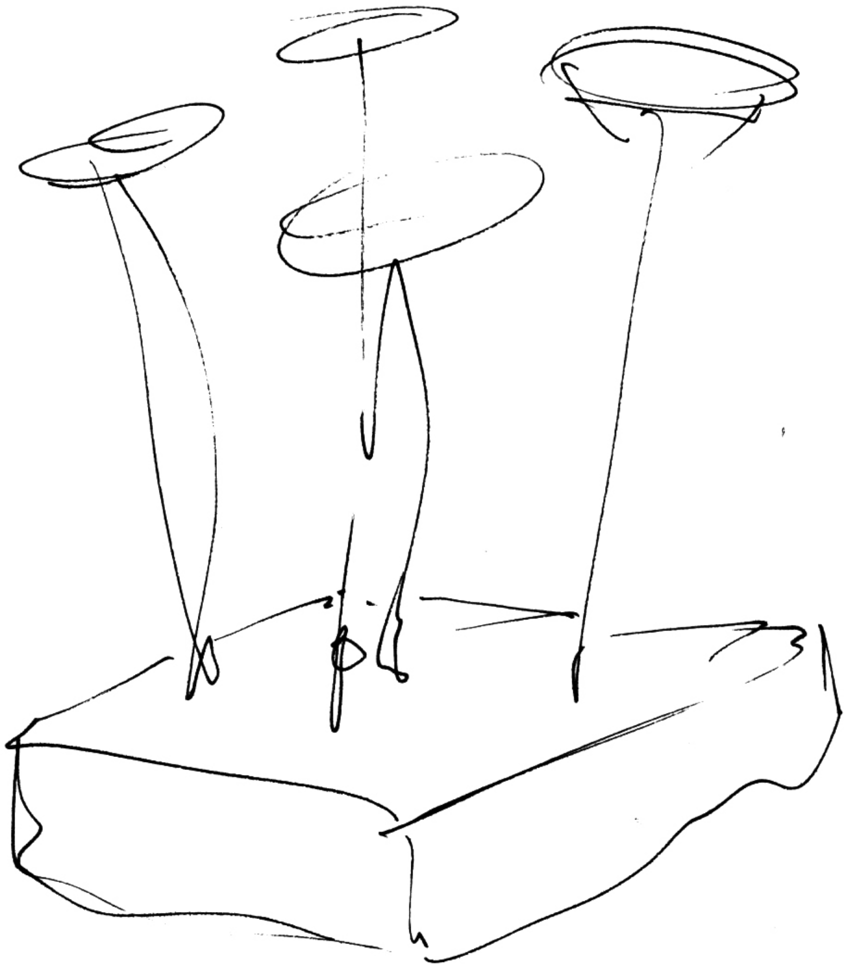
Tangible Pods

A raw tangible user interface (TUI) for

audio and haptic feedback



Bachelor Assignment for Rawshaping Technology

Peter Schaefer • February 2015

University of Twente • Industrial Design • Faculty of Engineering Technology

Tangible Pods: a raw tangible user interface (TUI) for audio and haptic feedback

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Summary

This Bachelor Assignment (BA) is a contribution for the development of tangible interfaces that support multi-sensory perception, metacognition and physical manipulation. The assignment is to explore, experiment and test diverse ways of creating tangible user-interfaces (TUI) that support visual, tactile and auditory interaction and afford audiovisual feedback and assistive responses (i.e. cues, nudges). Furthermore, part of the assignment was a study on the impact of interaction modalities on embodied cognitive processes. A user-centered design approach was applied in combination with a bottom up iterative design process and a prototyping phase. Iterations were made based on a vision and requirements for an interaction that supports the user by allowing him/her to use his/her hands for 3-D physical manipulation to create sounds in a playful and synthesized way. The vision and requirements are based on earlier work from the Free Assignment (FA) and research done about the theory behind Rawshaping Technology (RST), other related work and embodied cognition.

The iterations have lead to three concepts of which one has been further developed into a prototype. The prototype is an implementation of the concept for the exploration of sounds with tangible interaction. It shows that the concept is feasible using relatively low-cost technology (piezos and pressure sensors, compression springs and an Arduino microcontroller). With the prototype a small usability test was executed. The test results suggest that learning how to use the interface is not very difficult. It has been tested with people with and without cognitive impairments to test whether there is a difference in perceived usability. However no conclusions about this could be drawn from the test and further research is necessary. Lastly, conclusions from the test were drawn and recommendations for further development in concept and execution were made.

Samenvatting

Deze bachelor opdracht (BO) is een bijdrage aan de ontwikkeling van haptische 'user interfaces' die gebruik maken van multi-sensorische perceptie, metacognitie en fysieke manipulatie.
De opdracht is het exploreren, testen en experimenteren met diverse vormen van 'tangible user interfaces' (TUIs) die visuele, haptische en auditieve interacties ondersteunen en audiovisueel en ondersteunend feedback (b.v. 'nudges') genereren. Daarnaast wordt als deel van de opdracht een studie uitgevoerd over de invloed van interactie modaliteiten op 'embodied cognitive processes'. Een op de gebruiker gefocuste ontwerp-aanpak is toegepast in combinatie met een 'bottom-up' iteratief ontwerpproces. De iteraties zijn gebaseerd op een visie voor een nieuwe soort interactie die de gebruiker ondersteund door drie-dimensionele, fysieke interactie met de handen om te zetten naar audiovisueel feedback. De visie is gebaseerd op eerder werk van de Vrije Opdracht (VO) en onderzoek over de theoretische achtergrond van Rawshaping Technology (RST), ander gerelateerd werk en theorie over 'embodied cognition'. Bovendien zijn er eisen, wensen en specificaties opgesteld gebaseerd op dit onderzoek.

De iteraties hebben geleid tot drie concepten waarvan een verder is ontwikkeld tot een prototype. De prototype is is gemaakt als implementatie van het concept voor het maken en exploreren van geluiden met haptische interactie. De prototype laat zien dat het ontwikkelde concept technisch haalbaar is met relatief goedkope technologie. O.a. werden piezos, druksensoren, veren en een Arduino microcontroller werden gebruikt voor de prototype. Met de prototype is een kleine 'usability-test' uitgevoerd, waaruit bleek dat participanten in de test relatief snel konden leren met het ontwerp om te gaan. Een deel van de mensen die hebben deel genomen aan de test zijn mensen met autisme, om te testen of er een verschil in waargenomen gebruiksvriendelijkheid is in vergelijking met mensen zonder autisme. Hierover konden geen resultaten worden getrokken, omdat meer onderzoek uitgevoerd zou moeten worden. Ten slotte is het resultaat geëvalueerd en zijn conclusies uit het project getrokken.

Preface

With this assignment I got the opportunity to do exactly what I wanted to do, therefore it is really dear to my heart. During my bachelor in Industrial Design Engineering I have come to be more and more weary of designing products and found more excitement in creative applications of interactive technology, especially when they are used for making music. During the Free Assignment a new world of possibilities opened up for me and I learned about the many things that have been done by professionals and hobbyists. This inspired me to learn how to do the same and expand my vocabulary as a designer by learning how to use these technologies. This assignment was also the longest, most detailed and most difficult design process I have gone through so far.

Facing the challenge of having to design something from the ground up that has to work and live up to my vision has given brought me more experience.

I want to thank Robert Wendrich for seeing the vision I had in mind, having confidence in me and pushing me to achieve more. And thanks for all the coffee.
Furthermore, I want to thank Steven Waanrooij for showing me how to solder and giving advise on technical solutions. I also want to thank Joyce Van Dalfsen and Edwin Dertien for helping me find participants for testing the prototype. Finally, I would like to thank Betina Van Meter for her moral support in times when I was feeling overwhelmed.

Assignment

The objective of this assignment is to explore, experiment and test diverse ways of creating tangible user-interfaces (TUI) that support visual, tactile and auditory interaction and afford feedback (i.e. cues, nudges) and assistive responses. Also part of the assignment was a study on the impact of interaction modalities on embodied cognitive processes.
The aim is to design a hybrid design tool (HDT) for interacting within a virtual environment VE and to study the cognitive impaired (e.g. autism, cognitive impaired, developmental disorders) in support of meta-cognitive skillfulness and deficiencies.

List of abbreviations

2-D = two dimensional
3-D = three dimensional
AAS = Active Acoustic Sensing
ADHD = Attention Deficit Hyperactivity Disorder
ASD = Autism Spectrum Disorder
BA = Bachelor Assignment
CAD = computer aided design
DoF = degree of freedom
FA = Free Assignment
GUI = graphical user interface
Gyro = Gyroscope
HCI = Human-computer interaction
HD = high definition
HDT = hybrid design tool
IC = integrated circuit
ICT = information and communication technology
IDE = integrated development environment
IEK = Intuition-Experience-Knowledge
IF = interface
IMU = inertial measurement unit
IR = infrared
IxD = Interaction Design
JUI = jamming user interface
MIDI = Musical Instrument Digital Interface
MSS = Malleable Silicone Shape
MUX = multiplexer
NUI = natural user interface
PDD = Pervasive Developmental Disorder
Piezo = piezoelectric element
RFID = radio-frequency identification
RSFF = Raw Shaping Form Finding
RST = Rawshaping Technology
SFCS = Swept Frequency Capacitive Sensing
SUS = System Usability Scale
TP = Tangible Pods
TUI = tangible user interface
UI = user interface
VE = virtual environment
WIMP = windows, icons, menus and pointers

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1. Introduction

Computers mostly work with visual cues and windows, icons, menus and pointers (WIMP) interfaces and keyboard and mouse devices to interact with them (Beaudouin-Lafon, 2004) [1]. Tactile cues are sometimes used as well, but in less prominent and/or obvious ways. Recently, TUIs have been developed that integrate physical objects in virtual interaction to bridge the gap between the digital and physical realm (O Shaer et al., 2010) [2]. While most graphical user interfaces (GUIs) are based on the desktop metaphor, the physical world offers a large amount of stuff in a plethora of contexts that one can physically interact with in many ways. However, the division between these two worlds is starting to crumble (Hornecker, 2011) [3], because of TUIs among other things. TUIs allow users to create and interact with digital data in a physical way. They often support multisensory perception and make use of physical objects, instruments, architecture or spaces (Ullmer, 1997) [4]. This report describes the development of a TUI for audio(-visual) and haptic feedback. The interface is called Tangible pods and it aims to foster abstract thinking processes through tangible interaction. The interface was developed for Rawshaping Technology (RST).

1.Structure

The report for this assignment is structured around its process. First, the analysis of theories and work that influenced the design process is laid out. It starts with describing preceding work done in the Free Assignment. Then the RST approach to Human-computer interaction (HCI) and design processing is explained. This forms the basis for the approach to this assignment. After that, a summary of other work in three related fields of study (TUIs; JUIs and NUIs) is given and the influence on the Tangible Pods concept is explained. Next, a detour into touch sensing that was not further pursued in the design process is briefly described. Finally, to explore interaction for people with autism the role of theory on embodied cognition and music therapy are described.

In the next chapter, the ideation and conceptualisation phase is laid out. It starts with a description of the vision that fueled the process. Then the visualized iterations and the resulting three concepts for the interface are presented. Next, an overview of sensors that can be used for measuring physical interaction is given. After that, the feasibility of some of these concepts were tested with simple test set-ups. Then one concept was chosen and more iterations on the concept were made to explore its possibilities.

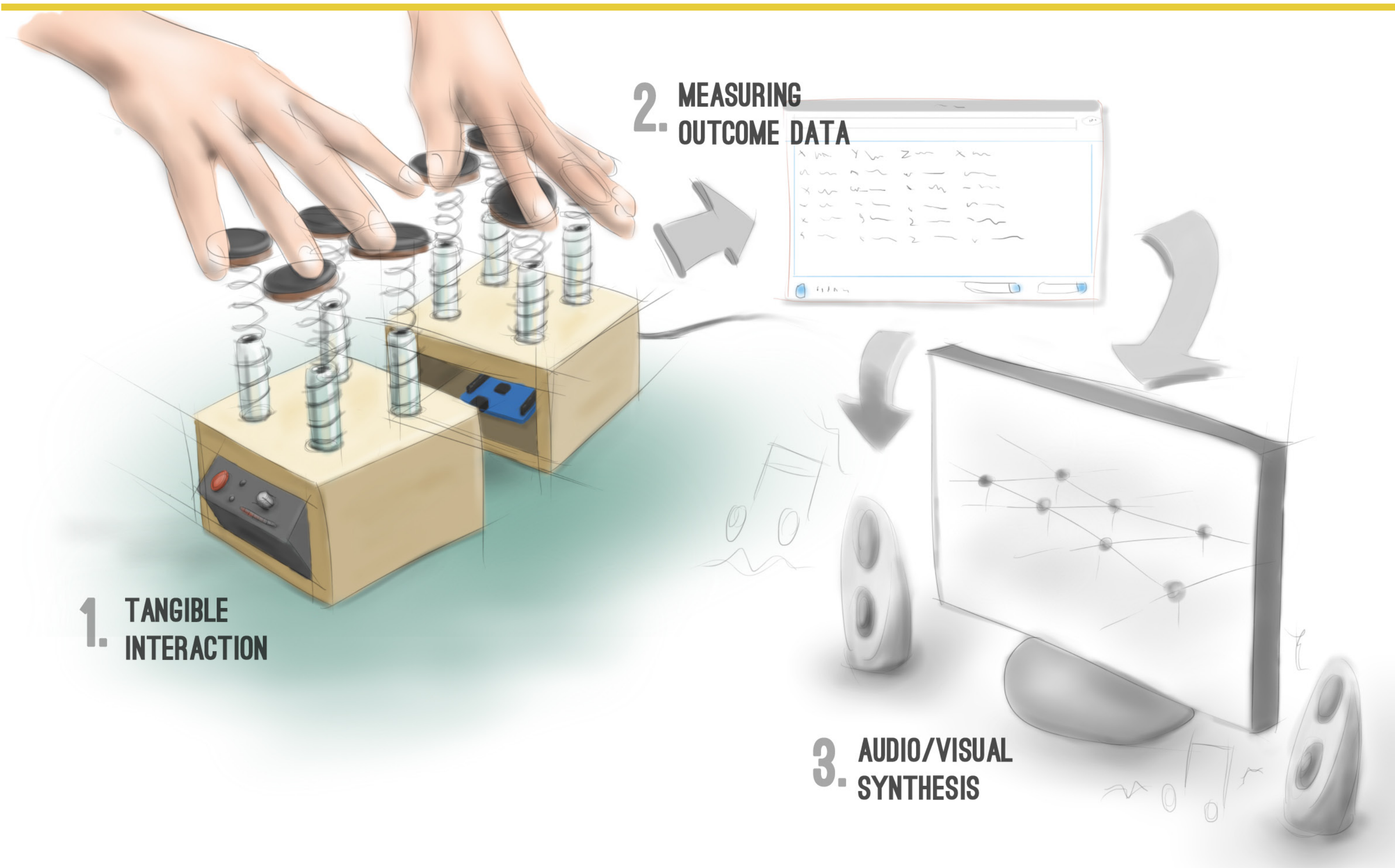
In the prototyping phase one concept was chosen for further development into a prototype. First, design decisions that had to be made in order to make the prototype are laid out. Next, the dimensions of the prototype were defined in dimensional drawings. Then the process of making the prototype is explained. From drawings and a plan of action the prototype was manufactured in the workshop at the University of Twente. The process of writing the software that maps the data from the sensors to sounds is also explained. After that, the quick usability test that was executed with users is laid out. With results from this test and the aim of the assignment in mind the concept and the prototype were evaluated. The evaluation and the conclusion are presented in the next two parts. Furthermore, recommendations for future work are laid out.

2. Tangible Pods

Tangible Pods is a tangible user interface that consists of multiple “pods” that form a surface and can be physically manipulated/sculpted to create input data. It is a flexible interface that can be used in a range of applications including music, 2-D and 3-D modeling (see figure 1.1).

The interface is made for instant creation and self-expression through sound and visuals using computer technology. It facilitates this by giving digital data a haptic manifestation. Similar to a computer mouse a physical action measured by a sensor is interpreted by the computer as input that feeds back to the user; only in this case the interaction is three-dimensional and supports three axes of rotation (six degrees of freedom). Tangible Pods is a hybrid and tangible interface, which makes it more intuitive than traditional

Figure 1.1 *Tangible Pods concept*



WIMP interfaces since the user can rely more on his/her knowledge of interacting with physical objects. Because of this it can facilitate participation of non-experts in e.g. electronic music making.

Figure 1.2 *Two-footed interaction*

Because I have an interest in electronic music the prototype (see figure 1.3) is an execution of the tangible pods concept that proves the feasibility of applying it as a musical instrument/synthesizer. In the prototype compression springs from steel wire serve as tactile feedback. Together with the soft neoprene fabric of the pressure sensors the springs create a tactile richness. Pressure sensors, piezos and an accelerometer are used to measure the physical input and an arduino microcontroller is used to process the resulting input data which can then be sent to a variety of music programs (i.e. any that works with MIDI data). The prototype has four pods for practical reasons (see Design decisions), but the number can be changed to better fit the application's needs. The pods could could for example be embedded in an application that supports physical manipulation with two feet (see figure 1.2).

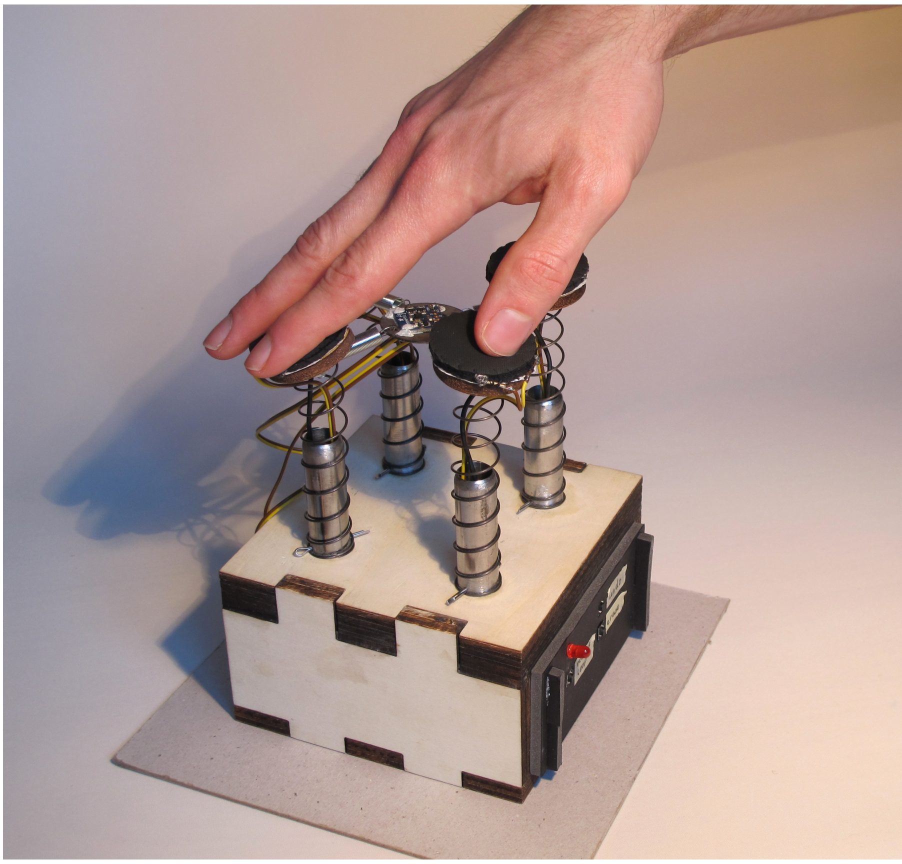


Figure 1.3 *Tangible Pods prototype*

2. Research and development

This chapter lays out the theory and work that the Tangible Pods concept is based on. It shows that the envisioned interaction is based on the kinetic sand interface from the Free Assignment. The aims of developing an interface are based on a theoretical background ranging from Rawshaping to tangible bits, JUIs and NUIs. Furthermore guidelines for achieving these aims retrieved from related work are presented in this chapter. The importance of designing for people with autism spectrum disorder and the cognitive disabled is justified. Furthermore, the implications of embodied cognition for interacting with digital technology are explored. Lastly, music therapy is analyzed as a possible context for a tangible music interface.

Figure 2.1 *Kinetic sand*

1. Kinetic sand interface

The design of the tangible pods is partly based on earlier work done during the Free Assignment (FA) for RST during my Industrial Design Bachelor at the University of Twente. During the FA, I developed a tool for the creation and manipulation of audio and sonification using kinetic sand (see figure 2.1). The prototype creates a hybrid connection between material and audio. The design is successful on the tangible side as the sand provides a very pleasurable texture as haptic feedback. However, the technology that synthesized the interaction into sounds did not provide the users with a feeling of being in control. The interaction was based on piezoelectric elements and computer vision. The sand was placed on a foam board platform (see figure 2.2|2), where it could be manipulated. The piezos are mounted under the foam board platform and pick up vibration that are caused by the sand being moved across the surface of the platform. The computer that the piezos are attached to determines peaks in the vibration signal and sends a MIDI signal to Ableton Live -a music production program- which results in a sound. So every time the user touches the sand or moves it a sound is played in varying amplitude depending on the amount of vibration.

Above the platform an HD (2.2|1)webcam is placed, which is used to determine the position (X and Y) on the platform. A second webcam (2.2|3) is placed on the right side of the platform to determine the height (Z) of the manipulated sand. These values are used to control pitch and effects.

Intermezzo

To get a better grasp on what the kinetic sand interface does, please watch a video of a user playing with the sand that can found in appendix 9 (on the attached DVD).

The interaction of the kinetic sand interface is based on the piezos and a computer vision system comprised of the two webcams. Using the piezos worked well and some users found it surprisingly intuitive. The computer vision was more difficult to implement and there were problems with precision, calibration due to inconsistent lighting and differentiating between the sand and the hands of the user.

For this assignment the goal was to develop a similar tool but this time using a different interaction technology instead of computer vision.

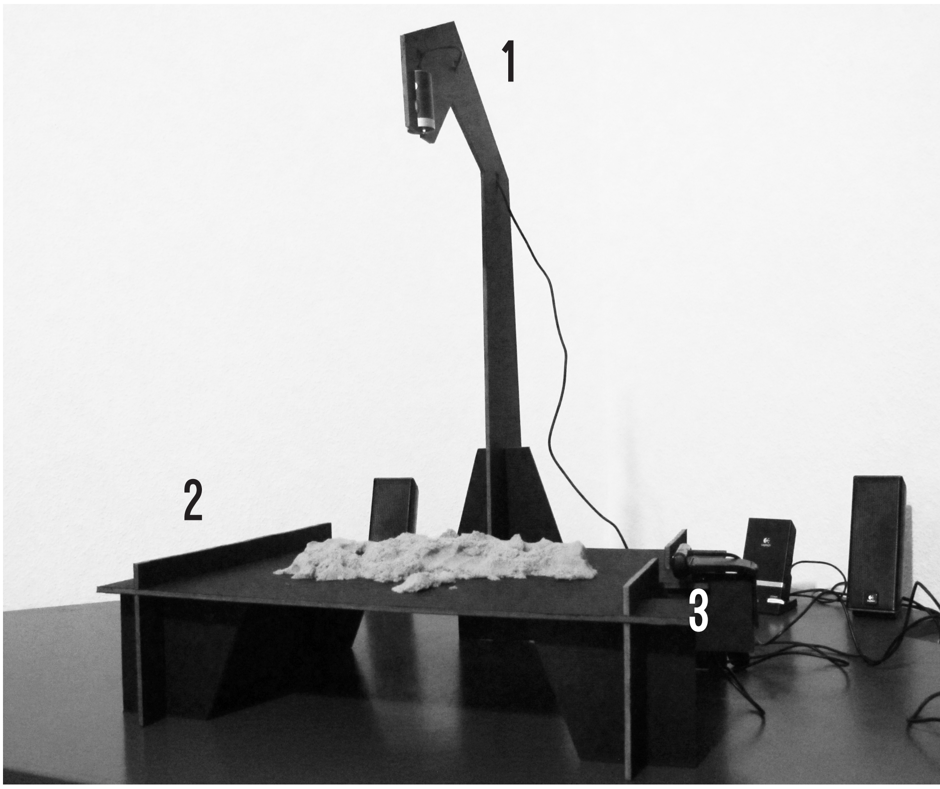


Figure 2.2 *Kinetic sand interface*

2. The Rawshaping Technology (RST) approach

Rawshaping Technology (RST) is doing research on the ideation and abstract conceptualization phase of the design process. RST is also developing hybrid design tools that support the visualization of fuzzy notions informed by tacit knowledge and allow the user to reflect on raw ideas. RST aims to foster designers to be creative and explore uncommon ideas they recognize to have potential. According to Kruiper (2015) the raw idea is larger than and different from the understanding of others, that might be reluctant to it [5]. In the following some important concepts that form the basis of the Rawshaping approach are laid out.

Tacit knowing

According to Polanyi (1966) in order to gain knowledge we process our experiences and sensorial input to form comprehensive entities [6]. By combining perceptions with non-perceived information more abstract and complex comprehensive entities are formed. This is how we can recognize a face without being aware of all of its elements. Knowledge gained from learning experiences is harder to express the more complex it becomes. According to Grant (2011) "…tacitness is something personal, an ability or skill to do something or to resolve a problem that is based, in part, on one's own experiences in learning" [7].

Polanyi (1966) differentiates between proximal and distal tacit knowing [6]. The focus lies on the distal part which is the comprehensive entity, which is comprised of proximal parts of which one is only subsidiarily aware of. The perception of the proximal parts is influenced by the tacit knowledge of the distal part. As an example Polanyi (1966) states that the human body is an instrument that is not perceived as such, so the distal entity of the body is actually included in the proximal and one becomes less aware of it [6]. Just like we perceive the world through our body, we perceive an artifact (digital or physical) we are working on through the tool we are working with. When one becomes proficient at using a tool, like e.g. a bicycle the focus shifts from how one is sitting on and balancing the bike to staying on path while moving. The same thing happens in a creative process when one is in a state of flow. According to Csikszentmihalyi (1990) [8] flow is a state in-between unselfconscious immersion during performance of a task and reflection-in-action (Schön, 1983) [9] leading to fast choice making. Other forms of reflection informed by tacit knowing in a creative process are reflection-in-conversation, reflection-in-practice (specialization through repetition of actions) and reflection-on-action (after the action was performed) [9].

Usability and hybrid tools

RST, Robertson et al. (2009) [10] and Kosmadoudi et al. (2013) [11] see a deficiency in usability in computer aided design (CAD) systems. Usability in an artifact or system is defined by its affordances and the sequence of actions needed to achieve an affordance. Affordances in Interaction Design (IxD) are what an artifact or system allows its user to do, understand, see, hear, feel or taste. How difficult performing an action with a tool/artifact is perceived to be depends heavily on how familiar the user is with performing the action to achieve a certain thing. No interface is truly intuitive in the sense that the user does not need any knowledge to use an artifact (Spool, 2005) [12]. By interacting with the world around them people learn how to interact with it. When an interaction is built on this tacit knowledge it is perceived to be intuitive [12].

Visualisation with CAD systems is often perceived to produce unsatisfying results (Bilda et al., 2005) [13]. They often require the user to perform a complex sequence of steps that have little to do with the actions performed in a physical design process and are thus not familiar. This results in a high threshold in learning curve. Furthermore current CAD systems do not afford ideation, flexibility, ambiguity and visualizing fuzzy notions [10]. Similar complaints apply to virtual music production tools like Ableton Live and Logic Pro. While they often offer great affordances that are not possible to achive with physical instruments, they have a high threshold in learning curve and do not foster fast, intuitive exploration of raw ideas.

Hybrid: merging physical and virtual representation

Wendrich (2012, 2014) proposes improving on the deficiencies in virtual design tools by combining the beneficial factors of physical and virtual representation [14, 15]. "We need to develop tools that allow the same subtle physical freedom and gestural motions traditional tools and instruments embody. Tools that support intuitive expressiveness, creative flow, rapid prototyping, allow speedy interaction and give sensory feedback" according to Wendrich (2012) [14].

These tools:

- Support skills and capacities in physical manipulation of the users
- Are flexible and provide the user with a wider range in affordances
- Encourage ambiguity and unpredictability
- Allow for rationalization by capturing every step in the creative process
- Allow for continuous reflection on thought and action through challenging between physical and virtual representation

Intuition-Experience-Knowledge (IEK) model

Wendrich (2009, 2010, 2012) proposes a process in which the design problem is approached holistically and intuitively [16, 17, 14]. In this approach the problem consists of multiple intimately interconnected parts that cannot be split up into sub-problems. This holistic approach, which is visualized in figure 2.3, allows the designer to connect existing and tacit knowledge to come up with uncommon, refreshing ideas.

The role of the designer is to explore these raw ideas, fuzzy notions and possible solutions through experimentation, externalization and play. During and after the externalization of ideas, the designer rationalizes and reflects on these ideas, which leads to new, richer iterations. McCullough (1996) argues we should learn and explore with our hands, because they are very subtle, sensitive, probing, differentiated and connected to the mind [18].

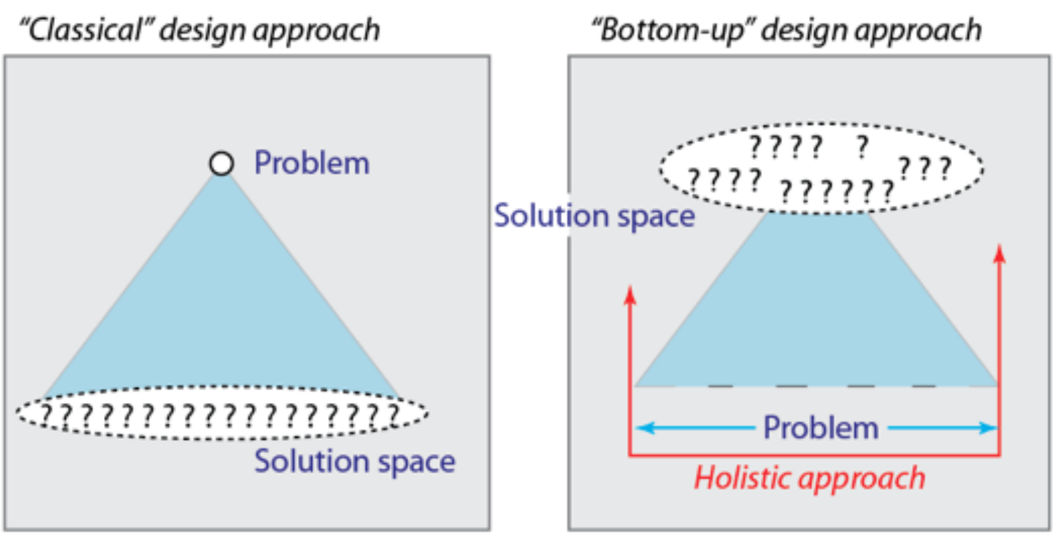


Figure 2.3 *Kruiper's (2015) visualization of the "classical" and the „bottom-up" design approach* [5]

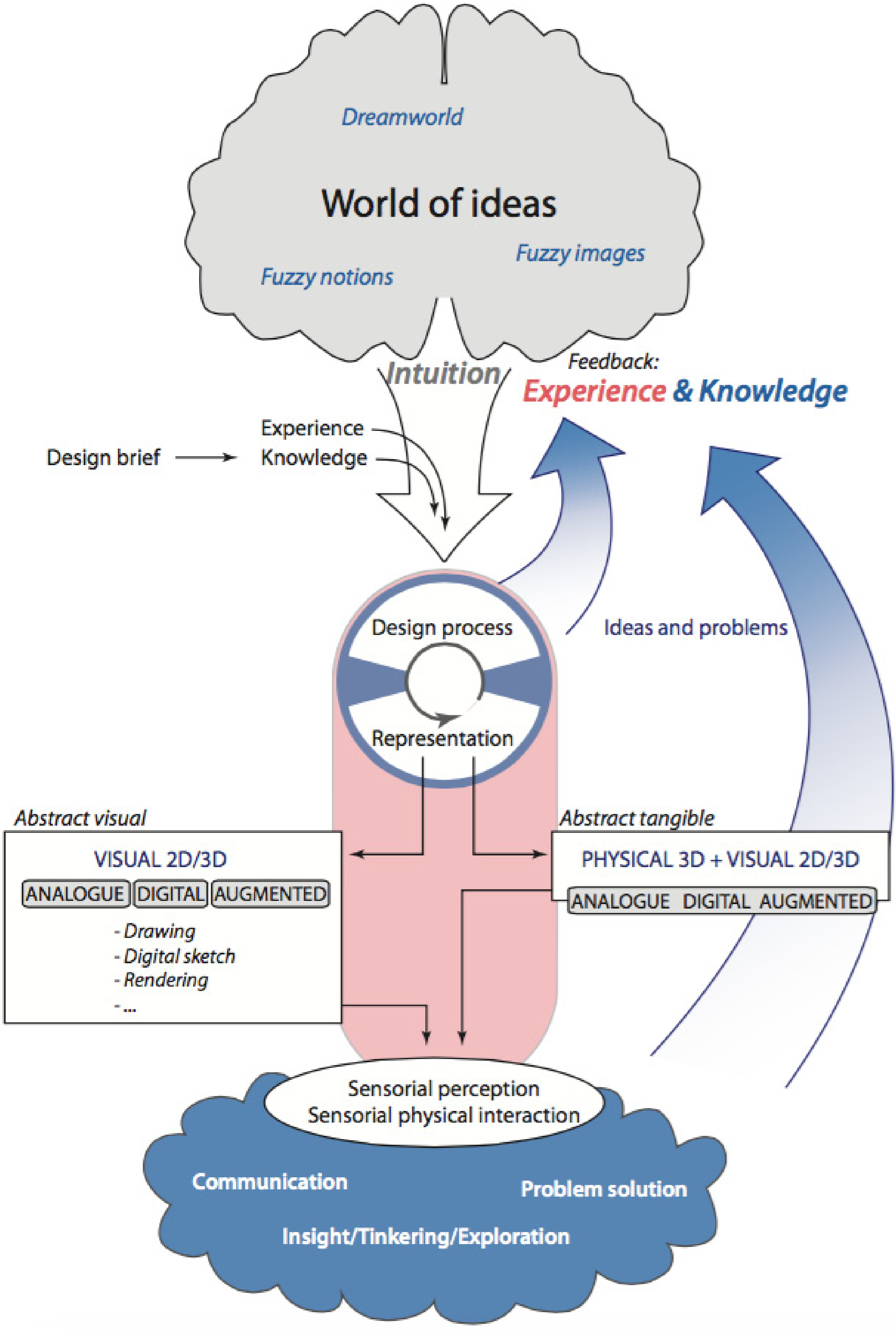


Figure 2.4 *Kruiper's (2015) overview of the IEK model* [2]

Through externalization in form the designer accumulates new tacit, personal knowledge about the scale, weight, texture, constraints and form of an artifact, which also informs the iterative process. The design process according to the IEK model is visualized in figure 2.4. Finally, a solution to the design problem can be found through incubation and reflection on the process.

Raw Shaping Form Finding hybrid design tool (RSFF HDT)

One of the tools developed by RST that serves as a good example for implementation of the Rawshaping theoretical background is the RSFF HDT (see figures 2.5-6). This tool captures physical objects and displays them as three-dimensional models on a touchscreen (2.6). This allows the user to iterate through two-handed manipulation of a physical, tangible object and then selecting, sorting, choosing and manipulating any of these iterations virtually (see figure 2.7). The interface also allows for collaborative interaction with multiple users on one or more tools.

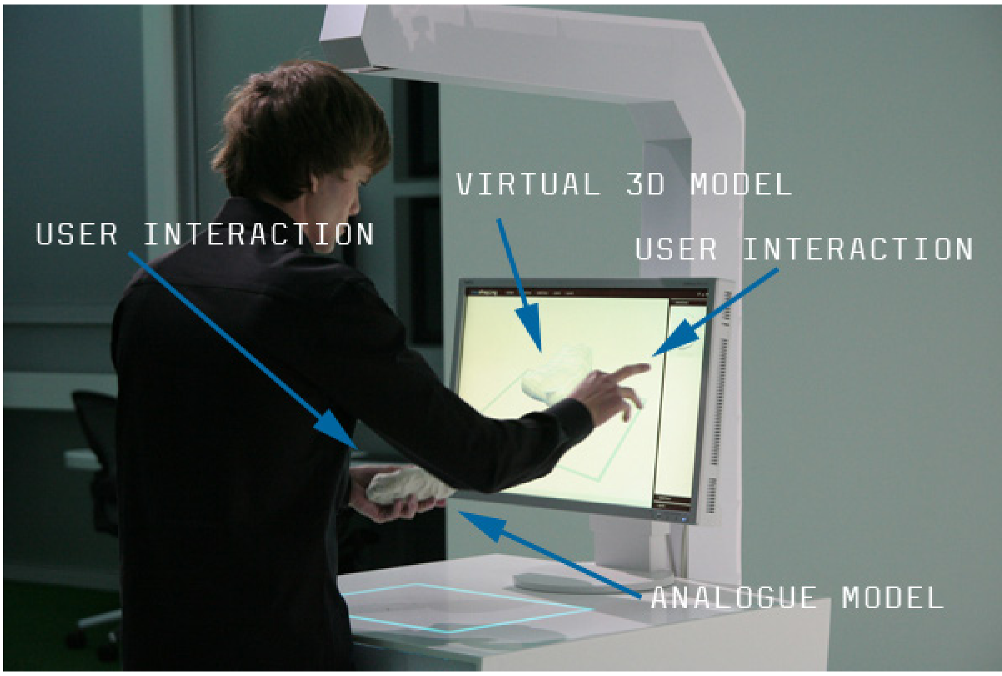


Figure 2.5 -6 *The RSFF hybrid design tool*

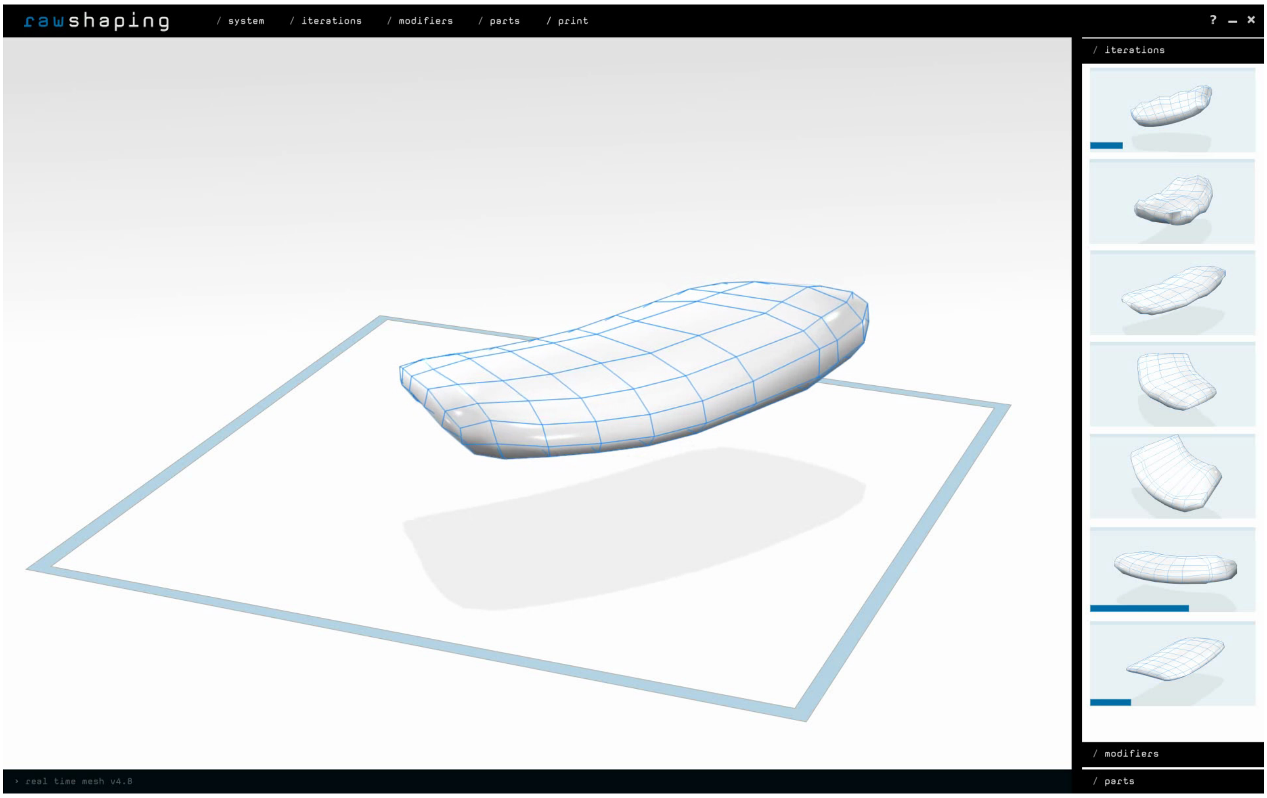


Figure 2.7 *Virtual 3-D iteration*

Implementation

The Tangible Pods interface (TP-IF) was developed for audio and haptic feedback, while RST focused on the development of hybrid tools for visual and haptic visualization, ideation and conceptualization in earlier and ongoing work. Still, parts of the Rawshaping theoretical background were implemented in the concept and final design of the TP-IF. The Tangible Pods prototype supports intuitive experimentation and expression in sound through tangible physical interaction. The interface could also be applied to combine visual and audio feedback, but for this assignment the focus is on synthesizing sound. The interface should allow the user to think in sounds and nudge him/her to explore uncommon sounds by introducing randomness into the process. Furthermore, it should improve on some of the usability deficits of existing music production tools (i.e. Ableton Live and Logic Pro).

The guidelines were used to develop requirements and wishes for the final design (see chapter 2.7).

These guidelines for the development of an intuitive TUI for audio and haptic feedback are derived from earlier work by RST:

The interface should

1. Mediate between physical and virtual representations
2. Support un-tethered two-handed tangible interactions
3. Facilitate tinkering & exploration of sound
4. Facilitate a process of iteration, synthesis and morphing
5. Allow for immediate interaction
6. Allow for intuitive expressiveness of the user
7. Be intuitively usable and give the user a sense of being in control
8. Facilitate getting into a state of flow
9. Support thinking processes and decision making in sound production
10. Support collaboration, conversation and back and forth signaling between multiple users using multiple tools
11. Support ambiguity and randomness
12. Support play and enjoyment

3. Tangible bits

Tangible Bits (Ishii et al., 1997) are digital data that can be accessed through interaction with tangible objects [19]. Ishii et al. (1997) establish three ways of bridging the gap between VE and physical environments:

- Interactive surfaces in an architectural environment that allow immediate access to a VE
- Hybrid artifacts that allow access to and manipulation of digital data belonging to a physical artifact
- Ambient media such as sound, light and temperature that influence and are influenced by users

Based on the framework of Tangible Bits, Ishii et al. (2004) developed digital sand and clay interfaces (Illuminating Clay and SandScape) [20]. Tangible Bits and the SandScape interface influenced the design of the kinetic sand interface.

4. Jamming user interfaces (JUIs)

JUIs are malleable and shape changing and perceived to be more organic than traditional interaction modalities, like mouse and keyboard or touchscreens. According to Follmer et al. (2012) there are two types of high-resolution shape sensing methods: Index-matched particles and fluids and capacitive and electric field sensing [21]. Follmer et al. propose the development of interfaces that are not only deformable and stay in form but can also be computationally actuated to change their material properties like stiffness [21]. They see that so far there have been more advances in shape sensing and mechanical actuation than in particle jamming, which is the computational actuation of material properties. An example for a JUI is Tunable Clay [21], which uses a hydraulic system to change the material properties and structured light depth sensing to measure deformation of the interface.

In contrast to JUIs, other interfaces that allow for haptic feedback provide information for the user by changing their shape. Haptic feedback can be categorized into active and passive forms of feedback. Passive feedback is the feedback a material provides because of its properties, for example; foams, springs and rubbers return to their original if deformed to a certain degree. Active feedback, or actuation, is when an active mechanism changes the form of an interface. In mechanical actuation this is often done using electrical motors. An example for an interface that uses mechanical actuation is Ros's (2015) 'Stewart', which is a tactile interface based on the Stewart platform [22]. The platform can move with six degrees of freedom (DoF), using six servomotors. It can also be used for haptic input, allowing for tactile communication between the user and the machine.

Mechanical actuation and particle jamming provide new ways of giving feedback to users, which have been neglected in traditional UIs. Even though in many buttons springs are used to provide passive haptic feedback, the full potential of passive feedback modalities have not been explored in traditional UIs. Furthermore, passive feedback is easier to implement in interfaces, because no motors or pumps are needed. Because of this, a choice was made to explore passive feedback modalities for the development of Tangible Pods.

5. Natural user interfaces (NUIs)

According to Jetter et al. (2014) computers still demand special skills from users and distract them with secondary tasks, like configuration of settings [23]. Instead they should offer immediate access to affordances "so that we are freed to use them without thinking and "mental gymnastics" and to focus beyond computers on new goals"[23; p. 1140]. Jetter et al. draw on the concept of conceptual integration to explain why computers can be very difficult to use. Conceptual integration is the idea that humans learn complex concepts like 'shame' or 'happiness' through integration of other less complex concepts. This means that basic concepts that can be learned through perception like 'up' and 'down' are connected to complex concepts through many steps of integration (Lakoff et al., 1980) [24]. This relates to theory on tacit knowledge, because one is mostly unconsciously using these concepts to carry out tasks. This also means that the mind has to be viewed as inherently embodied, because even the most abstract tasks are built on bodily experiences.

Jetter et al. state that computers are difficult to use because they require too many steps of conceptual integration and do not make enough use of simple concepts that most people have learned through interaction with the physical world and their social context [23].

If WIMP interfaces are difficult to use, because they are too abstract, complex and 'unnatural', how can we design VEs that are perceived to be natural? When interaction with a VE is closer to interaction in the 'real' world, it becomes easier for users to understand and use digital technologies. Valli (2006) also sees the necessity of hybrid interaction tools and virtual representation of artifacts that can be manipulated similarly to physical artifacts. He proposes the development of VEs that support natural interaction [25]. "Natural interaction is defined in terms of experience: people naturally communicate through gestures, expressions, movements, and discover the world by looking around and manipulating physical stuff"(Valli, 2006) [25; p. 1]. The key aspect of Valli's vision is to achieve spontaneous interaction through simplicity and physical interaction. According to him immediacy in interaction can be achieved by making representation of content, organization of information and the interactive device more and more simple and invisible [25]. As interactive technologies become embedded in and behave like the physical world users become less aware of the mediation taking place and the interaction becomes more natural.

Tangible Pods is –strictly speaking- not a natural interface. Although it features physical interaction, the virtual output data is mapped to sounds that are either digitally created or sampled sounds that were created by different physical interactions. This is because digital technologies offer a different range of affordances that should also be accessible to users. This is why the aim for Tangible Pods is offering a wide range of affordances through immediate, hybrid interaction.

6. Virtual environments for people with autism spectrum disorder (ASD)

The choice to study people with ASD in relation to novel computer interfaces was made based on the belief that the assumed average user of UIs does not exist and studying people that do not fit the norm could possibly enrich the design process and help developing interfaces that adapt to the user's needs instead of the other way around. Rajendran (2013) argues that researching the relationship between people with autism and information and communication technology (ICT), is important for three reasons [26]:

- It can say a lot about affinities and aversions of people with autism
- ICT offers many opportunities to intervene, support and facilitate skill development in people with autism
- It can give new insights into human-computer interaction in general

The affinities and aversions of people with autism also make this field of research very challenging, as they vary greatly between individuals. To this day we have no full understanding of the disorder and according to Happé et al. (2006) it is probably impossible to explain it with one theory [27]. There is however consensus that ASD is a pervasive developmental disorder (PDD) and theories on certain aspects of the disorder exist [28, 29, 30].

The purpose of this analysis is not to give a complete overview on theories on ASD, but to establish a basic understanding of autism and to develop guidelines to help with the development of a TUI in support of cognitive deficiencies associated with ASD.

A Brief description of autism

The ASDs are sometimes categorized into three types of autism, which are all PDDs: autism per se, Asperger syndrome and PDDs that are not otherwise specified [26]. However, recently some (Lord et al., 2012) abolished this categorization, instead differentiating in severity of the disorder [31]. According to the American Psychological Association (APA; 2013) symptoms of autism include persistent difficulties with social interaction and communication in different environments and repetitive behavioral patterns resulting in difficulties in social life or occupation [32]. These symptoms begin, but are not necessarily recognizable, in the early developmental phase [32].

Embodied cognition and autism

Rajendran defines autism as a "disorder of social cognition, of cognition, of emotion, of perception and of movement" [26; p. 335]. All of these aspects also play a role in human-computer interaction. Addressing all of them in the design of a TUI would be impossible within the time constraints of this assignment. Instead, a choice was made to focus on embodied cognition and how the body's physicality influences psychological processes.

According to Antle (2009) there has been a shift from viewing cognition as a disembodied processing of signals to a process that requires physical and mental activity [33]. Antle says this shift to embodied cognition is one that should be taken into consideration in human computer interaction (HCI) especially the following three ideas in embodied cognition [33]:

- Meaning is created through spatial restructuring of elements in a (virtual) environment
- Physical actions can enhance and simplify cognitive tasks, e.g. physical manipulation can help learning the manipulation of mental models
- Bodily experiences can provide metaphors to help understanding abstract concepts, e.g. physical movement as a metaphor for progression in development ("look, how far I've come!" [33, p. 29])

Furthermore Antle describes how these ideas can be implemented in the design of user interfaces (UIs). Computer interfaces should feature tangible structures, which offer affordances through physical manipulation and/or allow for manipulation of virtual representations

[33]. This is similar to Wendrich's (2012) proposal for hybrid tools that merge the beneficial factors of physical and virtual tools [14]. Two examples for interfaces that implement object manipulation are the RSFF HDT through manipulation of the object itself and the tangible programming space (Fernaeus et al., 2006) [34], which allows users to solve programming problems by changing the spatial location of objects. Mental tasks can be simplified when physical interaction with a tangible is used as input [33], like in the example of the RSFF HDT.

"More abstract thinking processes can partly be traced back from physical movements"

Antle et al. (2009) developed a hybrid physical VE that maps full-body input actions to musical sounds [35]. In the development they found that tracing abstract cognitive processes from related bodily movements and using this for the mapping process improved the experience and performance of users. This suggests that more abstract thinking processes can partly be traced back from physical movements.

Music therapy for people with autism

The developed interface supports physical input and audio and haptic feedback, which makes it a musical instrument. Music therapy is often applied with people with autism. It is often applied to train sensory perceptions and expressing emotions in different ways. To better understand how musical instruments can be used in music therapy for people with autism I asked two people working with children with autism (see appendix: music therapy mails) to give their perspective. They contributed the following ideas that influenced the design of the interface:

- The learning threshold should be very low, like e.g. that of Lego-toys
- When playing with children with autism it works best to observe what the child is doing and to then join and copy the child in order to make a connection
- Catering to the child's interests, skills and context is important
- Setting goals for the child to have moments of success, can be very motivating
- Skills that therapists aim to support include expression of emotions, ideas and perceptions, building self-assurance, discovering one's own identity, social interaction and communication
- Music can support expression of emotions especially when the person has difficulties communicating with (body) language
- Children have individually different needs and react differently to music therapy

These ideas are by no means representative. They do however give a perspective on the context the interface might be used in. The ideas influenced the design process to a varying degree. Some influenced the concept directly, others were not directly taken into account. For example the assumption that there is a need for low-threshold tools that support a playful interaction and musical expression of emotions was reinforced. Furthermore, the idea that the interface should offer a wide range of affordances through simple but distinct sequences of action was supported. In the case of musical instruments this could mean allowing for a wide variety of sounds to be played through simple physical actions. Additionally, requiring only one action at the same time, while allowing for combination of actions keeps the learning-threshold low, while offering challenges for the users to achieve. The ideas also highlight the importance of communication and collaboration through music using one or more instruments. This means the interface needs to support use of at least two people at the same time and/or back- and forth- signaling between multiple users with multiple devices.

7. Conclusion: Requirements wishes and specifications

The literature research is summarized in a list of requirements, wishes and specifications, which were used to develop the vision that fueled the creation of iterations and concepts. The requirements are more essential to developing a concept that lives up to the vision than the wishes. The specifications informed decisions about the technical realization of the concept.

Requirements:
The interface
- Allows for manipulation of tangible material as an input modality
- Provides haptic and audio/visual feedback
- Mediates between physical and virtual representations
- Allows for simple, immediate interaction
- Allows for intuitive expressiveness of the user
- Facilitates tinkering, exploration, iteration and synthesis
- Is intuitively usable for people with and without a cognitive disability
- Fosters abstract thinking processes through tangible interaction

Wishes:
The interface
- Has a low learning-threshold and challenges more advanced users
- Offers a wide range of affordances
- Supports un-tethered two-handed tangible interactions
- Facilitates getting into a state of flow
- Supports collaboration, conversation and back and forth signaling between multiple users using multiple tools
- Supports ambiguity and randomness
- Supports play and enjoyment
- Supports decision making in sound production
- Gives the user a sense of being in control

Specifications:
The interface
- Achieves tangible interaction without using computer vision
- Provides haptic feedback using passive feedback modalities

3. Ideation and conceptualization

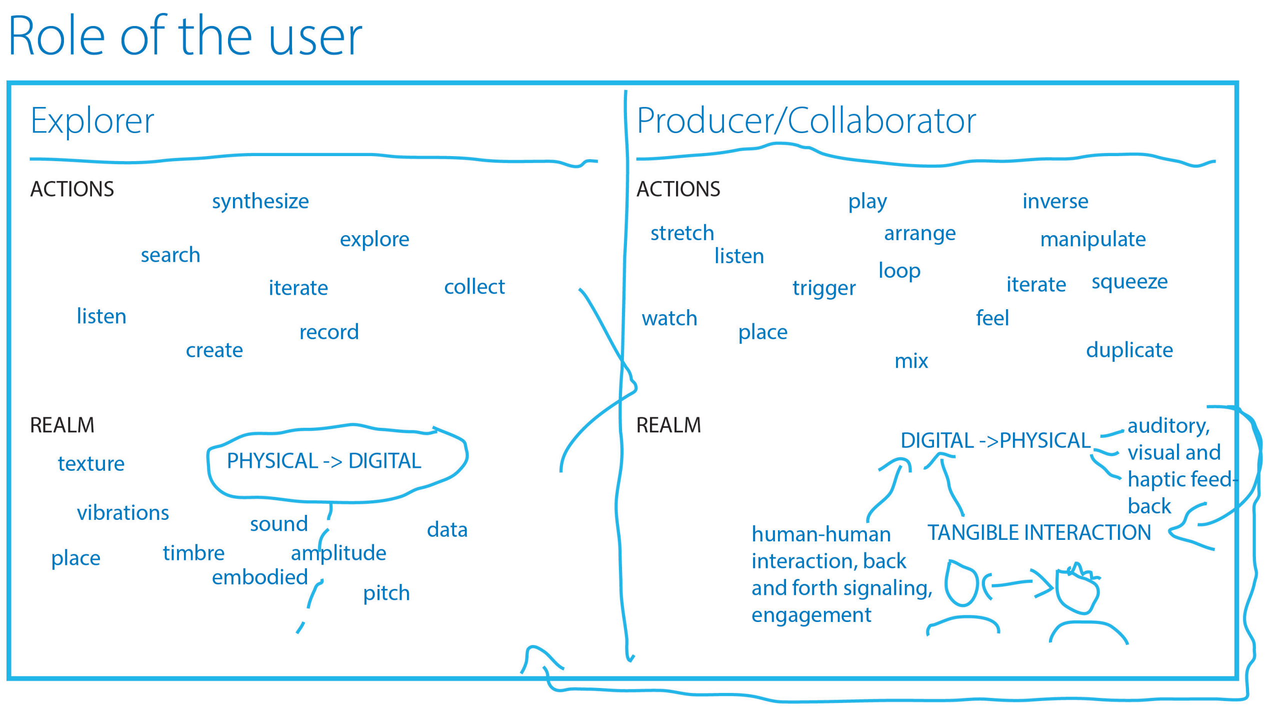


Figure 3.1 *Role of the user*

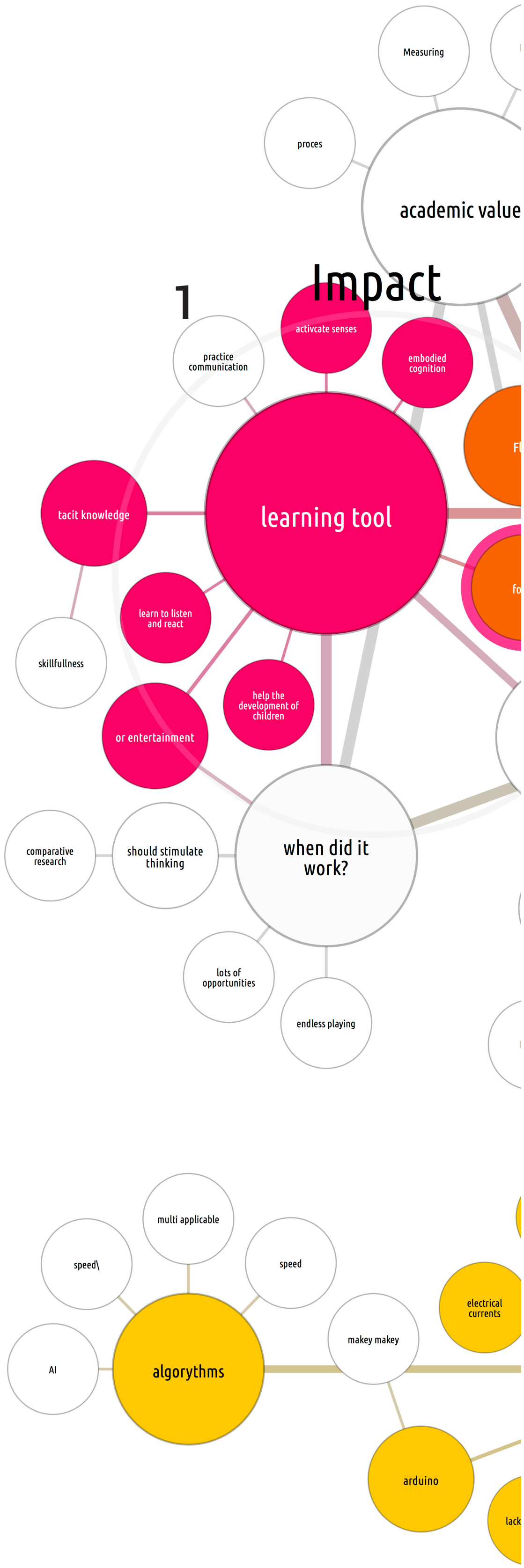
1. Vision

Central to this assignment is the interaction the user has with the interface. The interface is designed to allow for a natural, fluid interaction that supports haptic perception and manipulation. According to Jetter et al. (2014) [23] interaction with a digital environment is perceived as natural when the user can apply familiar concepts from interacting with his/her natural environment. With technology becoming increasingly ubiquitous, this so-called natural environment is already a hybrid one, but Valli (2006) [25] argues that knowledge about interacting with and discovering the physical world is something that should be applicable to digital devices. So in order to be perceived as more intuitive the interface should allow the user to spontaneously synthesize digital audio(-visual) data based on affect and intent by physically interacting with a tangible object.

The electronic artist Ash Koosha (2015) [36] describes his process as follows: "I stretch them [samples] like objects to see what's happening, which opens up a whole other world of sound". The interface is based on this notion of manipulating sound like objects. That way disembodied (synthesized or sampled) sounds can be played by physically interacting with the interface, reestablishing a (different) link between sound and material. Valli goes so far to argue that in order to be intuitive a digital artifact must behave almost exactly like the physical object it represents, however this approach is limiting to the possibilities (copying, reversing, etc.) of such a natural interface [25]. Difference in behavior of physical and digital artifacts might be counter-intuitive but will always exist with current technology. The resulting hybrid interface can still facilitate discovery, when the physical interaction is familiar but results in something unexpected. The role that the user can take using the different functionalities of the interface is visualized in figure 4.1. The interface should facilitate exploration of possibilties in digital sound synthesis through physical interaction. During synthesis the user should be able to arrange sounds into a composition (by e.g. looping them) and manipulate sound properties (e.g. timbre, amplitude, length, pitch). After that, the user should also be able to reflect on and change the composition and quality of the sound either through physical interaction or a simple button or screen-based interface. In contrast to gestural interfaces like Kinect [37], exoskeleton interfaces as e.g. developed by Jo et al. (2013) [38] and BodyCI like Myo [39], the aim is not to synthesize data directly from the movement of the body or muscle activity but to synthesize data from the interaction of the body with tangible material. The interface facilitates interaction with computers that is more fluid and natural, but also less precise. The output data has to be interpreted by a computer and translated into sound in a meaningful way. The interface can produce a diverse range of sounds from varying contexts and with varying intensity, pitch, duration and timbre. The data acquired by the sensors could be used for visual (2-D/3-D) interaction as well and be implemented in design processing. The interface gives the user access to possibilities of the digital realm, which are otherwise only accessible by learning software that is developed for professionals and therefore often has a high threshold in learning curve.

A wide range of people should be able to use the interface. Usability for the cognitive impaired was tested (see chapter 4.6). The users can use their hands to interact, manipulate and translate both digitally and physically in an intuitive, improvised, spontaneous and playful way. Furthermore, multiple interfaces should be usable at the same time, fostering interaction, back and forth signaling and engagement between multiple users (see figure 3.1). While it is theoretically possible for multiple interfaces to be used at the same time, testing this with users still needs to be done in further research as it lies beyond the scope of this assignment.

Figure 3.2 shows an associative map that was made to create a rough overview of the different aspects of the assignment. It was created using Phrasa*. The map was used to reflect on knowledge and associations regarding the development of a TUI for audio and haptic feedback and the aims behind it. In it, different ideas are visualized and related to each other. Colors were added to make the grouping of ideas visible. One of the things the maps shows are different ideas for interactions with tangibles that could be used in a computer interface (3.2|4). Moreover, first ideas on technologies that could make hybrid tangible interaction possible are documented in the map (3.2|5). The aspect of sound is placed in the center of the map (3.2|3) to show the focus on audio as an affordance. The map also shows that the required capacities (3.2|2) to use the interface are closely related to the user's experience and what he/she can practice when using the interface (3.2|1).



* www.phrasa.com

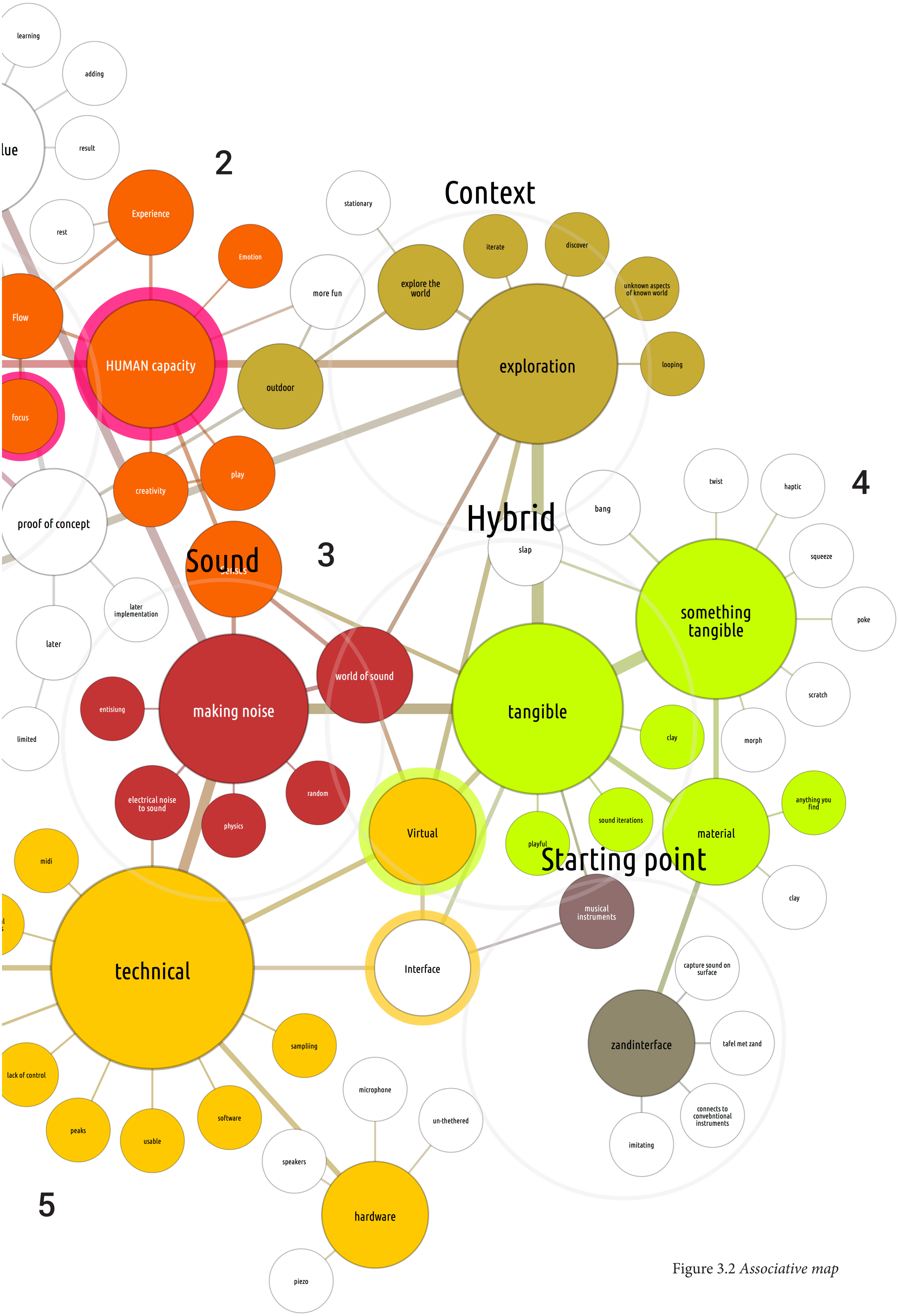
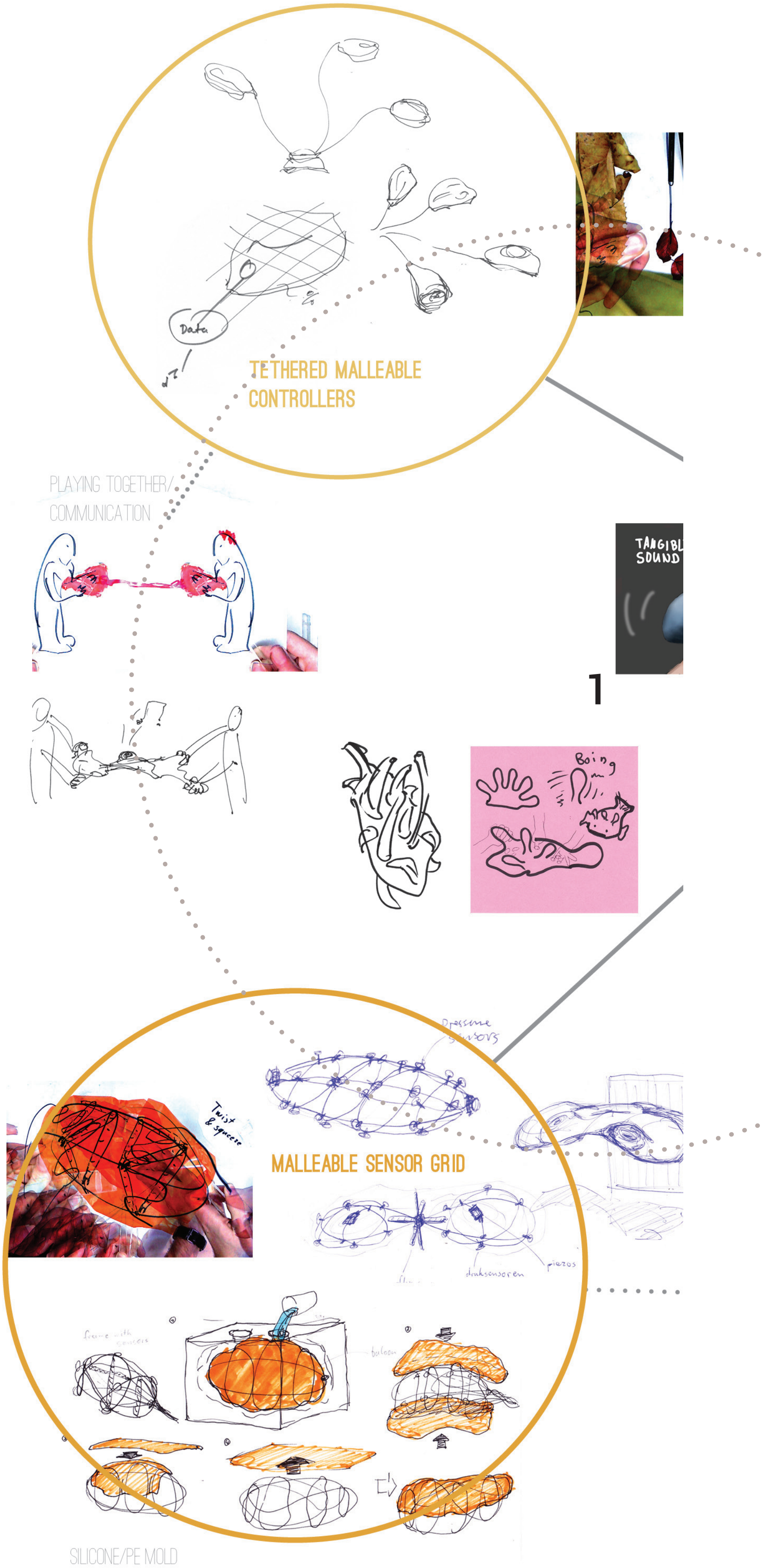


Figure 3.2 *Associative map*

2. Iterations

With the users, context and the vision of making sound tangible and graspable in mind, ideas were sketched and visualized to explore how the interface could work, look, feel and interacted with. One requirement was that it would not work with computer vision, because that technique proofed to be difficult to execute in the Free Assignment. When trying to implement computer vision for two-handed interaction the software needs to be able to tell the user's hands apart from the thing he is interacting with. Using kinetic sand as an interaction modality worked really well, because people want to touch it and it has a pleasant texture.

In the ideation process many iterations were made with the goal of emulating the interaction of playing with clay or sand and enhancing this with digital synthesis. The ideas can be sorted into three underlying concepts of how to achieve the desired interaction. Figure 3.3 gives an overview of the iterations and shows which concept they relate to. The first concept (3.3|1) is an malleable silicone objects that can be morphed due to its material properties and has sensors built in. The second concept (3.3|2) is a kinetic structure made of rods, hinges and springs that is also enhanced with sensors and the third concept (3.3|3) is a planar grid of tangible pods that can be manipulated three-dimensionally and also have sensors attached to them. For every concept, multiple iterations have been created. Those can be seen in the figure as well as sketches of some other ideas that were created in the process.



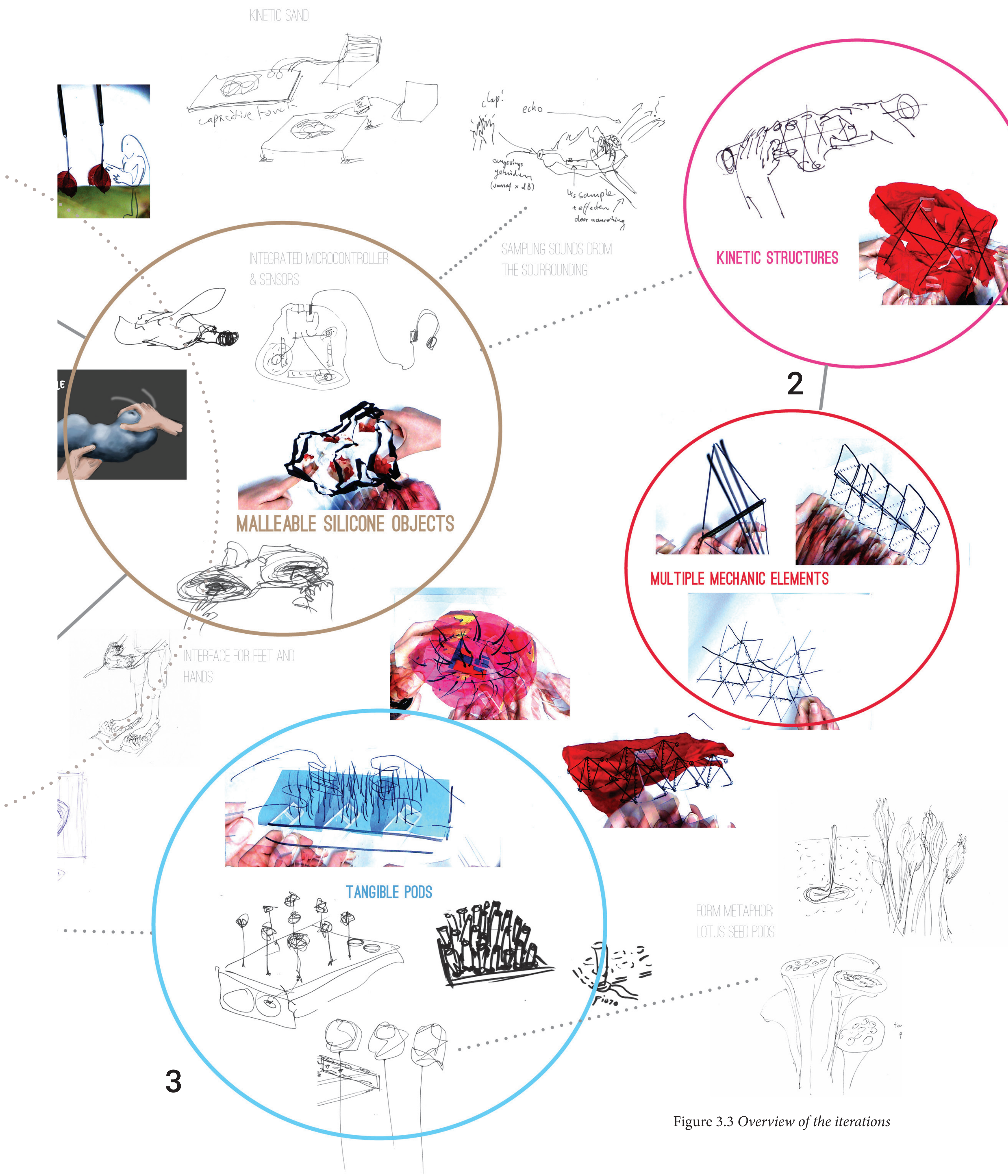


Figure 3.3 *Overview of the iterations*

3. Sensors for tangible interaction

To work out how the concepts can be realized, an overview of sensors that can be used for tangible interaction was made (see table 3.1). There are other possible technological solutions, but these were considered because they are relatively inexpensive, available and information on how to implement them is relatively easy to find. Computer vision was not considered for the technological solutions for reasons stated in the previous chapter (see chapter 2.1). The overview includes information on what the sensor does, what its advantages and disadvantages are and what tangible interactions it can be used to sense. The Arduino platform [40] was chosen to read outputs from the sensors. It is open source, easy enough to learn within the time constraint for the assignment and hardware is relatively inexpensive.

Sensor	**What it does**	**Pros**	**Cons**	**Possible application in tangible interaction**
Infrared (IR) sensor	Emits IR light and detects IR that is reflected by objects close by. Proximity can be determined using triangulation	Variety of reflectivity only has a small influence on proximity sensing	Relatively short range, only detects object in line of sight	Moving, approaching an object
Ultrasonic sensor	Measures how long it takes for emitted ultrasonic waves to travel to be reflected back to the sensor	Very precise, not influenced by visual characteristics of object, low-power	Only detects object in line of sight	Moving, approaching an object
Load cell	Applying a pressure to the cell changes its resistance. The resulting change in resistance needs to be amplified using a wheatstone bridge	Low-cost		Tilt, step on an object
Capacitive sensor	(see appendix 2)			Touching, approaching an object
Radio-frequency identification (RFID) chip and sensor	Detects electromagnetic fields emitted by a RFID tag	Tag can contain electronically stored data, does not have to be in line of sight	Some tags need power source, objects need to be tagged, 3-D location tracking still in development (Ko, 2010) [41]	Moving a tagged object

Table 3.1 *Sensors for tangible interaction*

Sensor	**What it does**	**Pros**	**Cons**	**Possible application in tangible interaction**
Flex sensor	Bending it increases resistance of the sensor, which leads to a lower output voltage		Only works in two directions	Twisting, bending a malleable object
Piezoelectric element (piezo)	Senses forces and small vibrations in material: when a force is applied it creates a proportional voltage	Low-cost		Tapping, kicking, hitting an object (and sensing how an object is touched in combination with vibration speaker)
Tilt sensor	Based on a ball inside the sensor that connects two pins when held upright, only detects if sensor is tilted in relation to the direction of gravity	Inexpensive	Does not detect amount of tilt or in what direction it is tilted	Tilting an object
Accelerometer	Senses static (gravity) and dynamic (motion) acceleration, can measure orientation in relation to gravity			Tilting, moving, shaking, throwing of an object
Gyroscope (gyro)	Measures angular velocity		Does not provide enough information to determine orientation	Rotating an object
Inertial measurement unit (IMU)	Combines data from accelerometers and gyros determine orientation position and velocity more precisely	Up to six degrees of freedom (DOF)		Tilting, moving, shaking rotating, throwing of an object
Force resistive capacitor	When pressure is applied resistance decreases		Not very accurate	Squeezing, poking, pushing, stepping on an object
Photocell	Resistance decreases with increasing light shining on the resistor	Low-cost, small, low-power	Not very accurate (50%+ variation)	Moving, approaching an object (e.g. hovering hands above sth.)

4. Concepts

In this section the three concepts are described and possible technological solutions to realize these concepts are presented.

Concept 1: Malleable Silicone Shapes

The Malleable Silicone Shapes (MSS) are controllers that can be touched, squeezed, morphed, and pinched. They are equipped with a microphone that records sounds from its surrounding like voices or claps (see figure 3.4). These sounds can then be sampled, manipulated and looped with the interface. Through physical manipulation of the shape the user can manipulate and play with the recorded sounds and (re-)discover familiar sounds. The physical manipulation changes the pitch and quality of the sound using effects like reverb, filters, etc. Sounds are played by squeezing or pinching the controller (see figure 3.5).

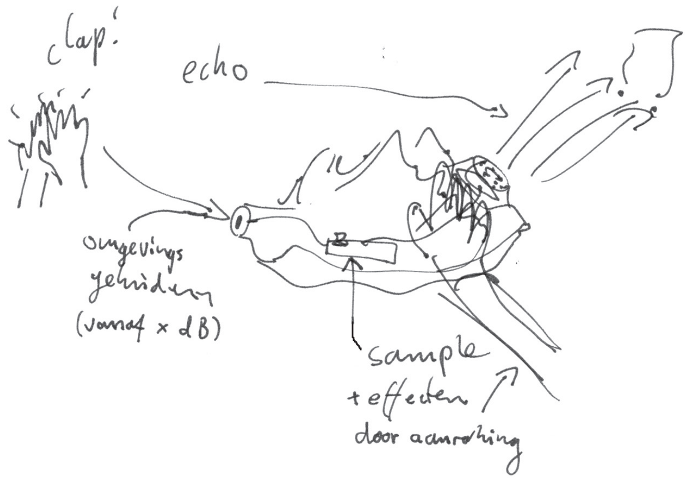


Figure 3.4 *Live sampling*

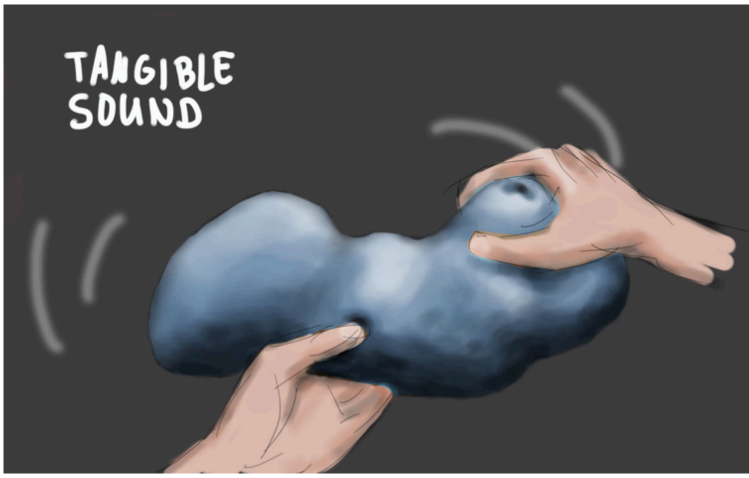


Figure 3.5 *Tangible sound*

The MSS contain an Arduino microcontroller that is connected to a piezo that senses squeezing and pinching and four flex sensors that sense whether the shape is bent and on which side bending occurs. The MSS could also have pre-recorded sounds to play with. Furthermore LEDs could be added for visual feedback (in transparent silicone). An accelerometer or IMU could also be added to the MSS to measure e.g. rotation and acceleration.

Sensor Grid
The Sensor Grid (see figure 3.6) is a different version of the MSS. It is a three-dimensional round grid made from steel wire that has flex sensors and piezos attached to it and behaves like a really soft spring. It has a covering layer of silicone on it but is hollow from the inside. The hollow inside is connected to the air outside with a small hole. The advantage of this version over the MSS is that the hollow inside allows for more deformation when it is being squeezed, but it is also harder to make such a shape with a silicone mold.

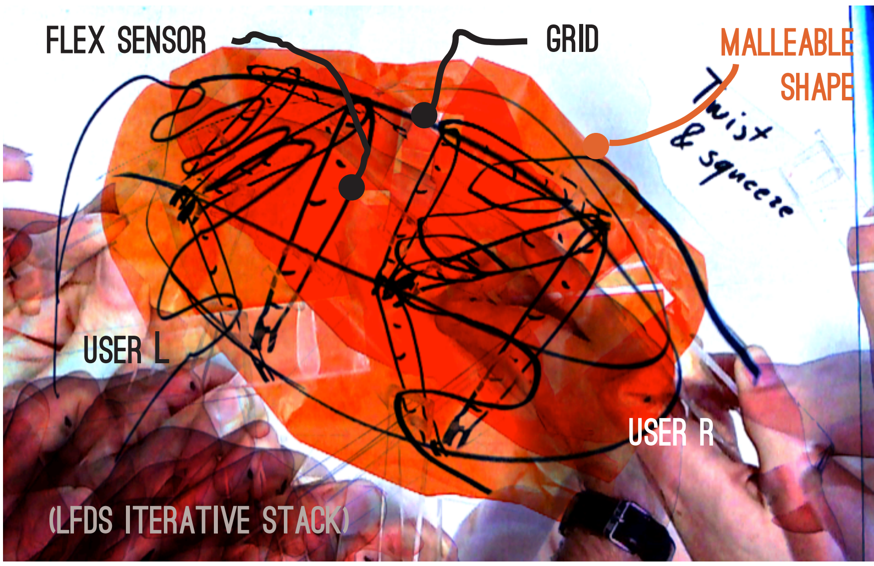


Figure 3.6 *Sensor grid*

Concept 2: Kinetic Structures

The Kinetic Structure is a long rod that has arms attached to it like a tree with branches (see figure 3.7). These arms are arranged in crosses perpendicular to the rod. The crosses arms are connected to the rod with a hinge, which allows them to rotate around the rod. The inner rod also has rotary hinges and can be formed. The arms could be connected to each other with pull springs, causing the structure to go back to its original form after being manipulated.

Each arm contains a gyroscope to measure its rotation. Sudden rotation gets translated into a sound with a certain pitch and angular velocity is mapped to the velocity of the sound. That way subtle manipulation results in subtle sounds and fast sudden manipulation results in louder (more abrasive) sounds.

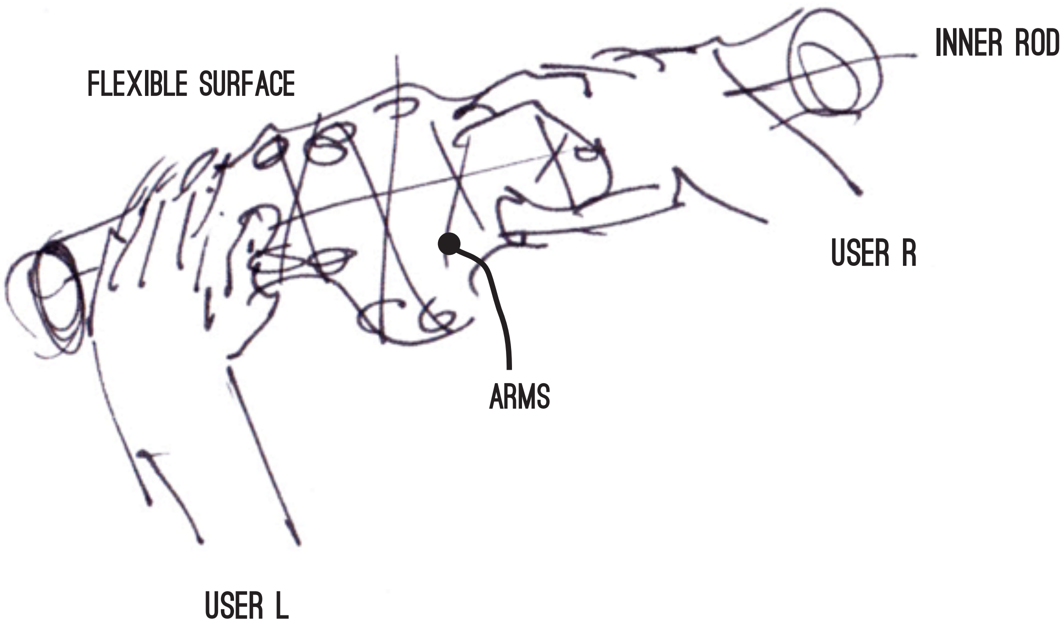
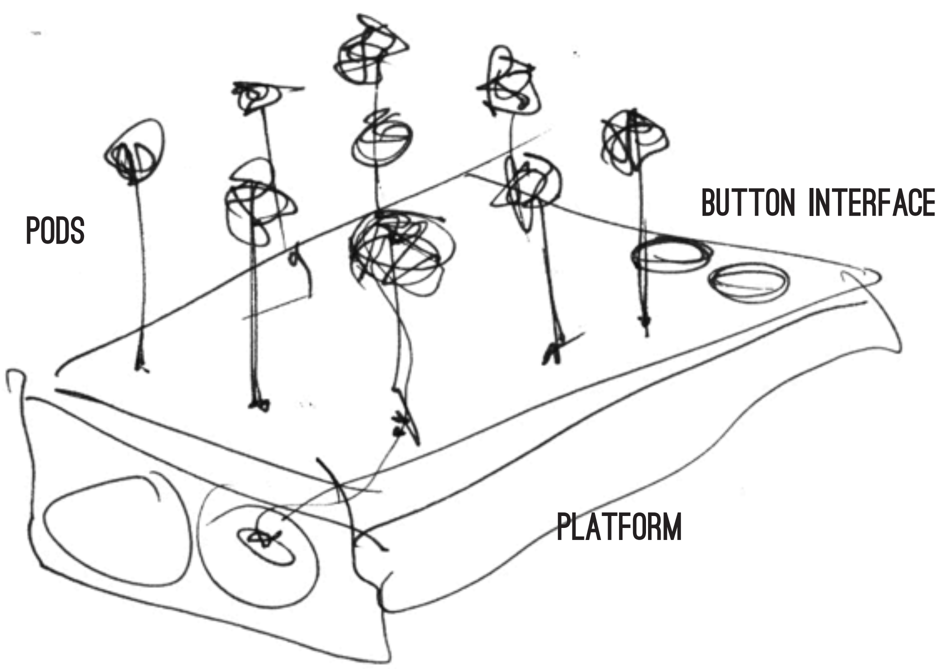


Figure 3.7 *Kinetic structure*

Concept 3: Tangible Pods

The Tangible Pods (TPs) are spherical-like shapes placed on top of flexible steel wire (see figure 3.8). They create a different note when they are tapped or pinched. The pods are placed on a platform that contains a microcontroller that processes the signals from the sensors. They can also be pressed down and tilted to the side, which changes the sound quality and pitch of the note. Tapping and pinching is detected using a piezo and the amount of pressure is detected with a flex sensor. The flex sensors are attached to the steel wire and bend when they are being pressed down. An accelerometer in each pod measures the orientation.

The user can also switch between the loop and the normal mode. When the user activates the loop mode, it (periodically) loop sounds that the user makes and give the user the ability to add to and take away from this loop.



Figures 3.8 *Tangible Pods*

5. Final concept

The three concepts are different manifestations of the same vision of a malleable, tangible interaction with computers. In contrast to the Tangble Pods concept the Malleable Silicone Shapes and the Kinetic Structures do not need to be placed on a surface allowing for handheld interaction. This might enhance the feeling of a 'natural' interaction, because most everyday objects can be picked up and held in two hands. However, the Tangible Pods concept was chosen for further development into a prototype because it is most feasible due to its relatively simple structure. With the chosen concept testing the sensors is possible in a relatively fast and easy set-up whereas with the MSS the sensors first have to be integrated into a silicone mold. Making a prototype was deemed most important because it allows for evaluation of not only the concept, but also the vision that lead to the concept.

4. Testing and prototyping

Figure 4.1 *Prototype*

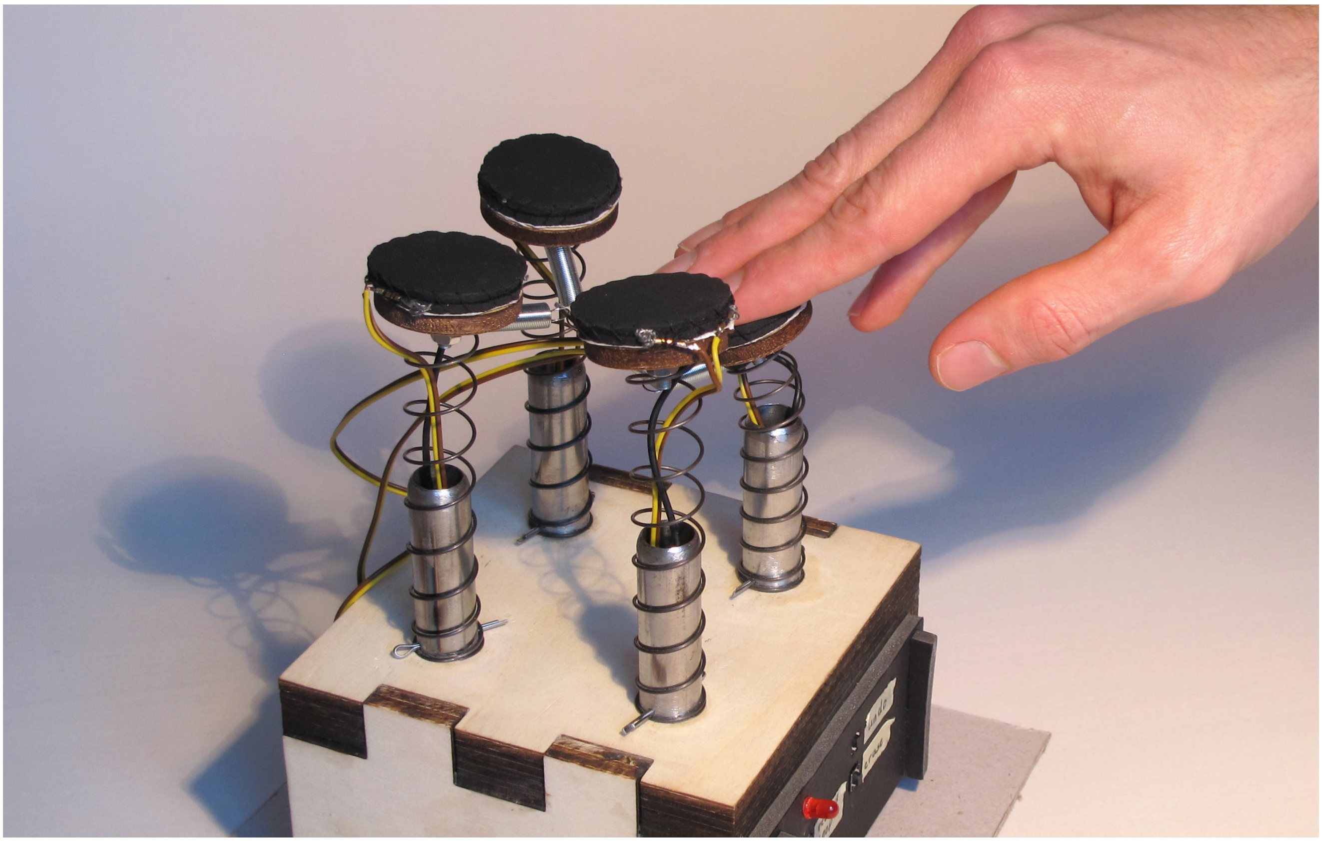


Figure 4.2 *Prototype with hand*

Figure 4.3 *Pods*

1. Sensor tests

The goal of these test set-ups was to quickly determine whether the Tangible Pods concept could work using piezos and flex sensors.

Sensor test 1 (version 1 & 2)

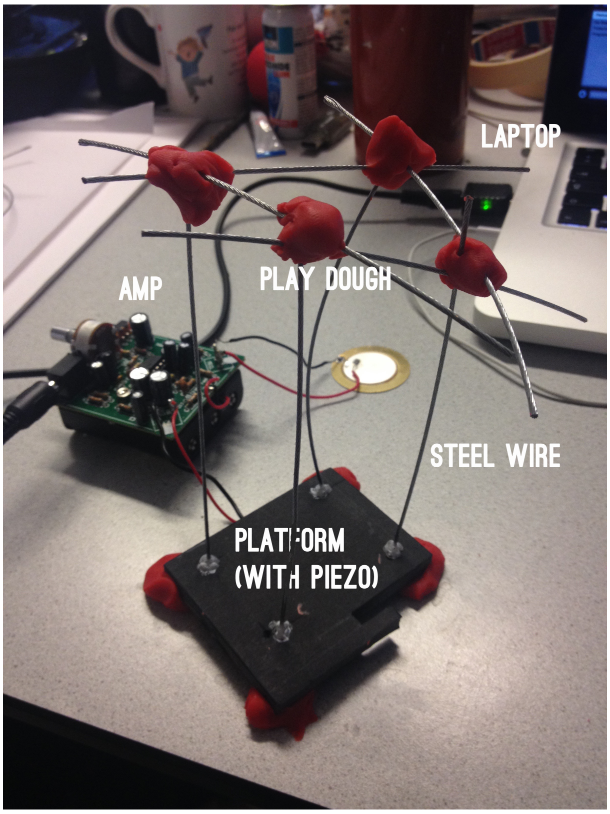
The first sensor test (see figure 4.4) consisted of a rapid model that is made up of steel wires glued vertically to a foam plate. Horizontal wires connect the tops of these vertical wires. At the intersections, the wires are connected with play dough. Because the play dough is not strong enough to hold the wire together when they are being moved, it is replaced by foam balls in the second version (see figure 4.5).

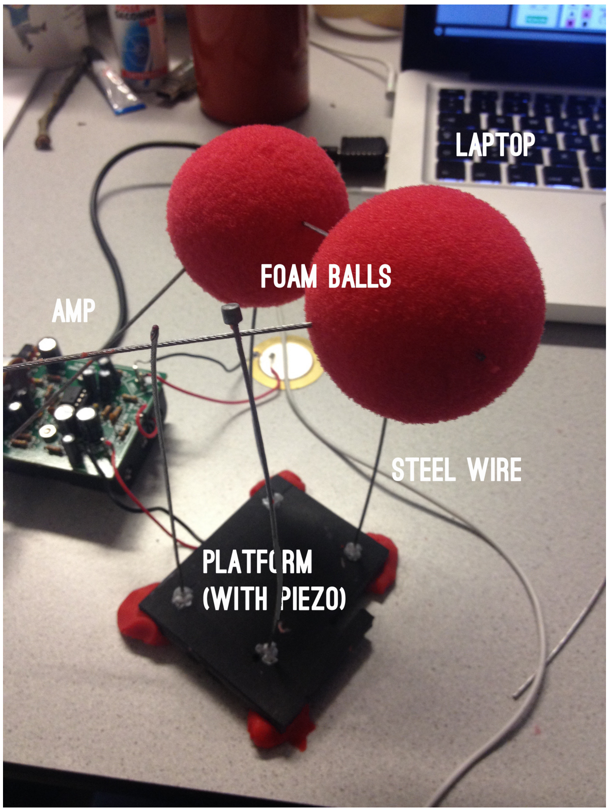
In version two the foam balls are glued to the wires. The only sensor in this test set-up is one piezo connected to an amplifier. The piezo is attached to the foam plate and detects vibration in any of the four wires. The signal from the piezo is fed into a computer for analysis. Every time the signal peaks this creates a sound. Peaks are determined by setting a threshold. The value of the peak determines the velocity (loudness) of the played note. The peak analysis is done in Max for Live [42]with two existing 'patchers' (Max for Live programs) called PEAKS and NOTES (Raz, 2013) [43] and sounds are triggered in Ableton Live (see figure 4.6).

Sensor test 2

The second sensor test (see figure 4.7) is similar to the first in that the parts are rapidly put together. There are only two 'pods', each consisting of two steel wires with a piezo and foam plates on top. The pods are not connected to each other so that they can move independently. The pods are glued to and standing on a foam plate on top of a steel plate, which provides weight and stability (see platform in figure 4.7). One of the steel wires has a flex sensor attached to it.

All the sensors are paired with an appropriate resistor and connected to an Arduino Uno. Piezos and flex sensors have a varying resistance so the appropriate resistor needs to be approximately equal to the





Figures 4.4-5 *Sensor test 1 (version 1 & 2)*

maximum resistance of the sensor. The resistor acts as a benchmark to how the resistance in the sensor is changing. The circuit looks as follows: 5 V (input voltage) -> resistor -> piezo/flex sensor -> ground. The analog pin is connected in between the resistor and the sensor. The piezo has a maximum resistance of about 1 MOhm and the flex sensor of 10 kOhm.

In this test the peaks in the signal of the piezo are determined with a program written in the Arduino Software (IDE). Every detected peak creates a MIDI note with a certain velocity depending on the value of the peak. These notes are sent to Ableton life using the Hairless MIDI to Serial Bridge. The value from the flex sensor is also converted into MIDI data and sent via a different channel to Ableton Live using the same bridge. The value can then be mapped to any value in Live. This test established the feasibility of the basic working principle for the prototype. The set-up is however too fragile and not a close enough approximation of the concept to be used for further testing.

Detour: Touch sensing

There was also a plan to incorporate acoustic touch sensing into the interface. Active Acoustic Sensing (AAS) is a technique to measure how an object is being touched (e.g. on which side) using a piezo and a vibration speaker. This was not further pursued for two reasons: using this technique requires know-how in the field of data acquisition and measuring three-dimensional physical manipulation is a more important part of the concept and should be pursued instead. More information about AAS can be found in appendix 2.

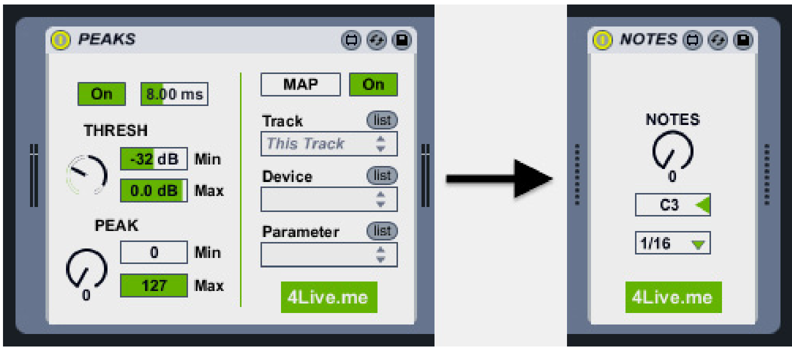


Figure 4.6 [32] *PEAKS and NOTES*

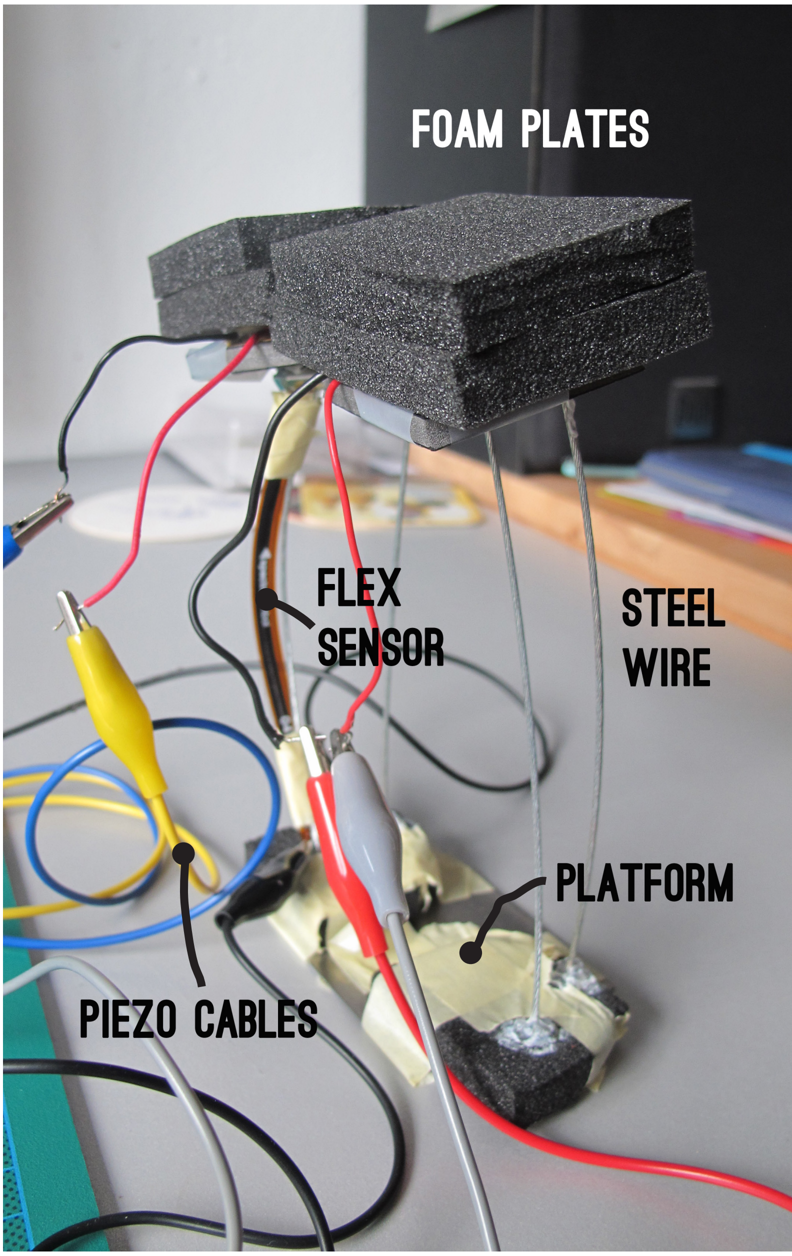


Figure 4.7 *Sensor test 2*

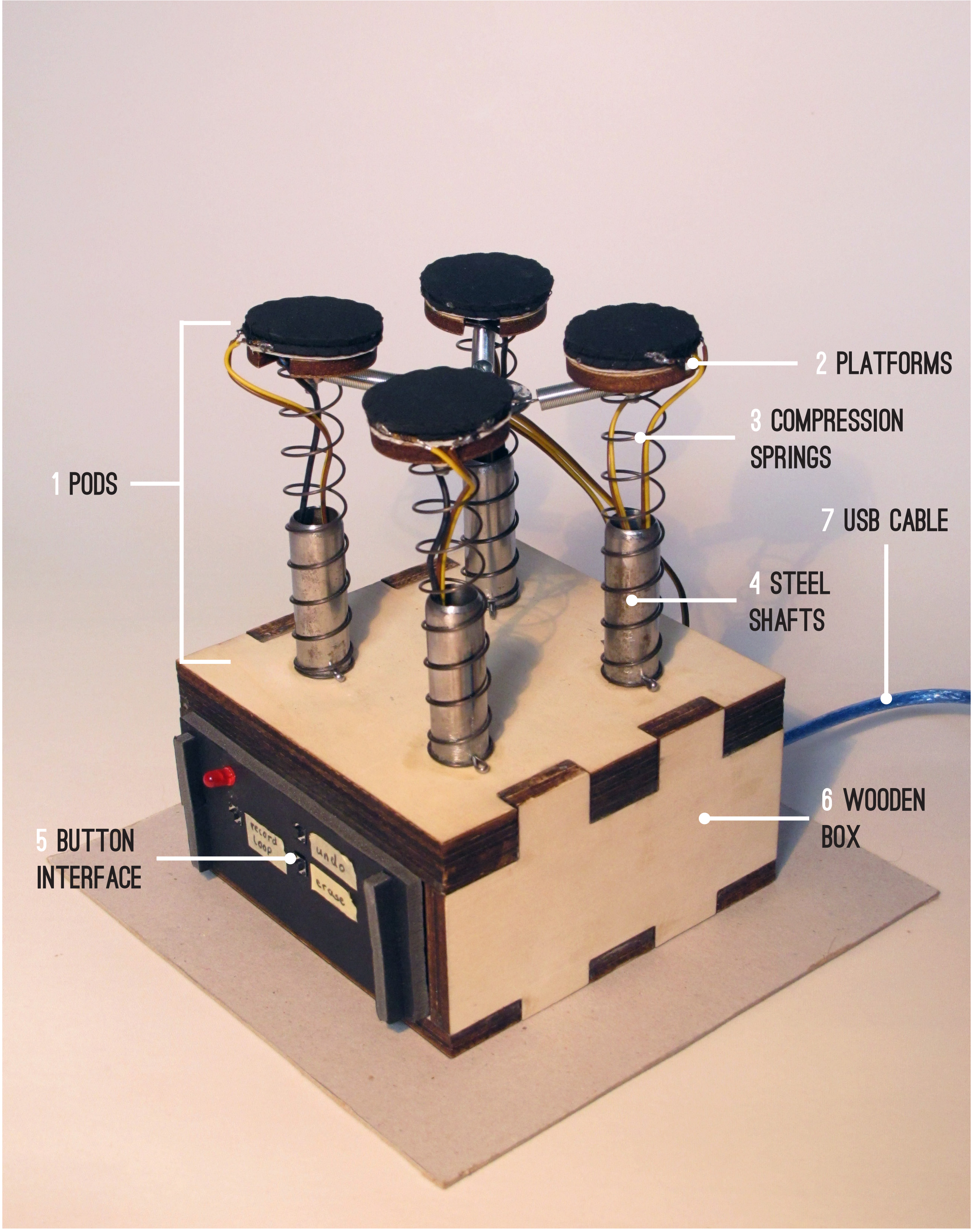


Figure 4.8 *Prototype parts*

The concept was further developed into a working prototype (see figures 4.1 to 4.3 and 4.8.). For this, a couple of design decisions about the dimensions of the prototype and the materials and tools for making it were made that are explained in the following. These decisions are informed by a preceding mechanical version of the prototype (see figure 4.9). For this early version of the prototype only the mechanical function was realized without the electronics. It was decided that a new version had to be made for reasons stated in appendix 3.

Springs

The steel wires that were used in the test set-ups are replaced by compression springs (4.8|3) in the prototype. They are better suited for being physically manipulated by the user, creating input-data (tilting, compression measured by sensors) and giving haptic feedback by going back to their original state. Furthermore, springs are available in a wide range of elasticity and sizes, which makes them suitable for applications of various scale and types of interaction. For example the concept of the tangible pods could then be scaled up to a size where one pod has to be moved with the whole hand or scaled down to a size where it could be put onto furniture and one could still sit or lie on it. To be used for a prototype, the springs had to be in a manageable size and quantity. Also they needed to be elastic enough so that multiple springs would be easily compressible with one hand. Three springs with different lengths, diameters and wire thicknesses were tested (see appendix: list of springs).

The spring that was chosen for the prototype is most suited because it is relatively easy to compress four of them at the same time due to the relatively thin wire thickness and it does not bend to the side as easily as the longer springs. It has a length of 100 mm, a diameter of 17,5 mm and a wire thickness of 1 mm.

Sensors

The sensors are a defining factor in the user experience as they translate analog input into digital data. Many different kinds of sensors have been used for tangible interfaces (see overview: Technology for tangible matter). Four piezos and pressure sensors and one accelerometer are being used in the prototype. The piezos pick up vibrations in the object they are attached to and were also used in the kinetic sand interface in the Free Assignment. In the prototype for this assignment they are used for detecting peaks in the vibration of the pods, to detect when the pod is being moved. Doing this with piezos is cheap and relatively easy to do, but not very precise. They can also pick up the frequencies of the vibrations, which can be used to determine where and how an object is being touched (see example), but this requires skills in data acquisition and analysis that goes beyond the scope of this assignment.

In addition to the piezos, pressure sensors are being used in the prototype instead of the flex sensors in the test set-ups. Pressure and flex sensors work in a very similar way. When pressed/flexed the output Voltage of the sensor is higher, because the resistance is lowered (Vout = Vin * (R2 / (R1 + R2))). Pressure sensors were used instead of flex because they can be implemented in the same way, so that when a pod is being pushed down, the it is being pushed down the higher the output value of the sensor is. The pressure sensors could be better integrated into the design, because they fit onto the round platforms (5.8|2), while the flex sensors do not fit into the inner diameter of the springs when they are bent. The pressure sensors are also hand-made instead of pre-fabricated, to make the prototype as cheap (see appendix: prototype cost calculation) as possible and also because size and material (neoprene) can then be chosen to fit the purpose.
Lastly an accelerometer was added to measure how the user is tilting the pods. Preferably every pod would be equipped with one of these, but for the purposes of a prototype, which is an approximation of a further developed artifact, using just one accelerometer is cheaper and sufficient to proof the principle. The accelerometer was placed on a small steel disc, which is connected to all four pods with extension springs, so that it moves with the pods but does not limit their movement too much.

Pods

Different arrangements and numbers of pods (4.8|1) were sketched and tested using just the compression springs. To make up an imagined surface that the user can place his palm on at least three pods are needed. The prices were calculated for all the parts for the different numbers of pods. Choosing four as the number of pods for the prototype was a good compromise in possible interaction versus price.

Wooden box

The pods were placed on a wooden box (4.8|6) that contains the Arduino and the electronic circuit. It is made from multiplex-plate, because that material makes it relatively light but not so light that it easily falls over. The plates for the box were laser cut with teeth at the connecting ends of the wooden plates, which made it easy to neatly glue them together with wood glue. The top plate is thicker than the others because this creates more surface for gluing the steel shafts into the holes in the plate.

Steel shafts

The steal shafts (4.8|4) are there to hold the springs in place and keep them from bending too much to the side. They are a little less then half the length of the springs to still give them enough freedom of movement. The steel shafts are hollow in the middle so that the cables from the sensors can be neatly run through the middle of the springs into the wooden box. The steel shafts have a small hole running through the shaft perpendicular to their long axis. These are placed just above the base of the spring so that the spring gets locked when a split pen is pushed through that hole, holding the spring between the pen and the box.

Button interface

The button interface (see figure 4.8|5 and 4.11) was added to the prototype to allow users to record and repeat sounds as described in the Tangible pods concept (chapter 4.4). The design of the button interface is based on the Ableton Live audio effect Looper (see figure 4.10). Looper can be used to record sounds into a loop that is periodically played back. The interface features three pushbuttons (4.11|2) and one LED (4.11|1). The buttons allow the user to access the functions of Looper. Every time a button is pressed the Arduino sends a MIDI note to Ableton Live that is mapped to a specific function of the Looper effect. The buttons were chosen as an interface modality, because they allow for very precise interaction with only two possible states (pressed and not pressed). To integrate the buttons into the prototype they are placed in a foam board panel (4.11|3) that can be inserted in one of the open sides of the wooden box.

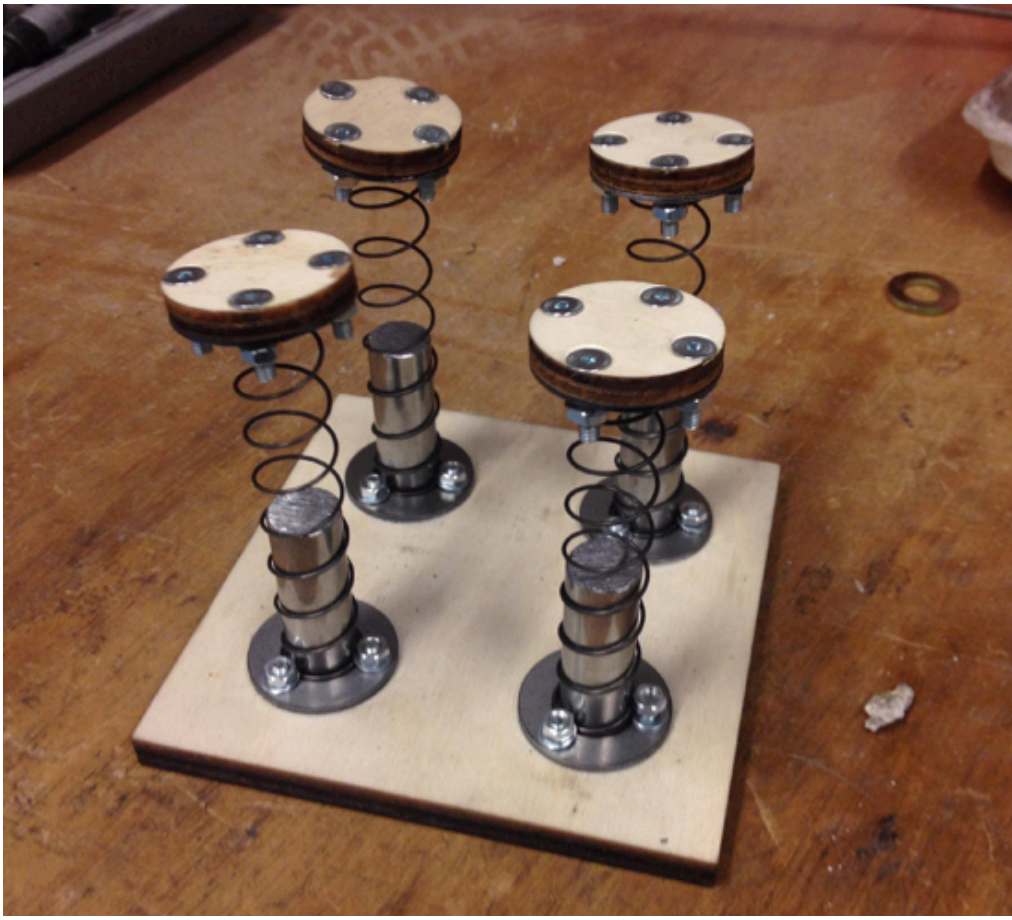


Figure 4.9 *Fully assembled mechanical prototype*

When the user presses the 'record loop'-button all the sounds he/she makes are being recorded into the loop. The red LED indicates whether the loop-function is enabled (red light means function is enabled). Pressing the 'record-loop'-button again turns off the loop-function. The other two buttons can be used to erase sounds from the loop. The 'undo'-button erases the last recording, starting from when the 'record-loop'-button was pressed. The 'erase'-button erases all the sounds in the loop. Originally, there were supposed to be two other buttons, one that doubles the length of the loop and one that makes the loop half as long. These two buttons were scrapped form the design to make it simpler. It was assumed that these two buttons would be confusing to users, as the interface does not display the length of the loop. To display the length of the sample or add additional functionality like erasing and manipulating specific sounds in the loop would have required a different technical solution. Another desired functionality that was not realized is the recording of sounds from the surrounding with a microphone and playing them back in a manipulated way. This was not possible due to the limitations of working with MIDI in Ableton Live. Live only allows for instruments that work either based on MIDI or audio signals. Adding more functionality would have required writing a program in Max/MSP or the Arduino IDE that works on its own without a digital audio workstation like Live. This would have required too much time and it would also mean that the interface could not give access to the wide variety of sounds that can be made in such an audio workstation.

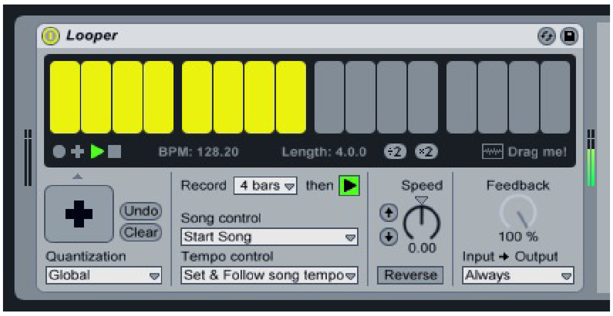


Figure 4.10 *Looper*

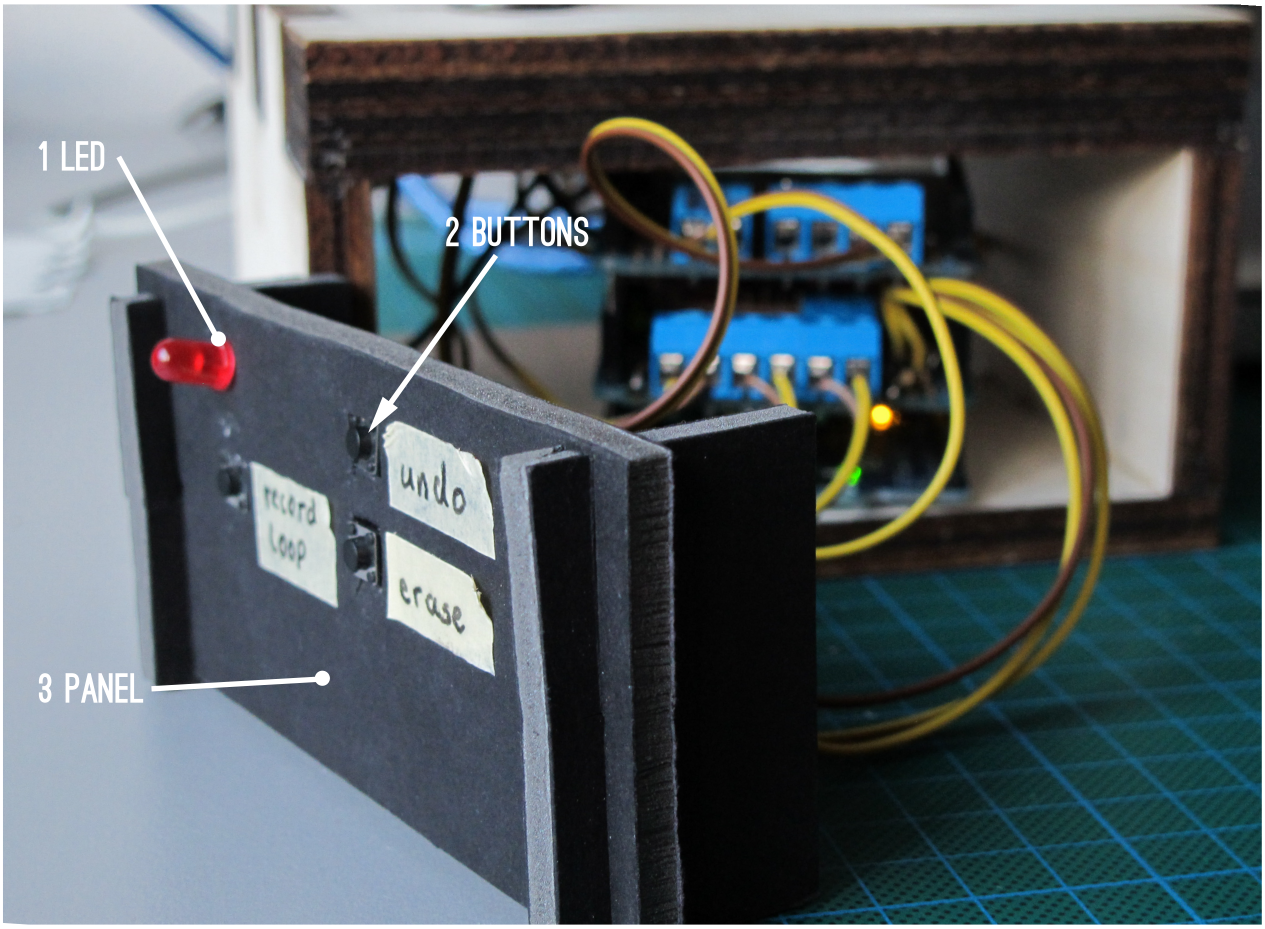


Figure 4.11 *Button interface*

3.Dimensions

The dimensions of the prototype can be seen in the dimensional drawings (figures 4.12, 4.13). The dimensions of the prototype were defined to fit the prefabricated parts and be suitable for interaction with one or two hands. The steel shafts (4.12|3) and disks (4.12|2) were designed to fit the dimensions of the compression springs (4.12|P1). The wooden box (4.12|4, 5, 6) was designed so an Arduino and two ProtoShields fit inside of it and the button interface (5.13) was designed to fit precisely into the open side of the wooden box. The wooden disk (4.12|1) and the pressure sensors have approximately the same diameter as the piezos. All of these parts are listed in table 4.1. In the sub-assembly drawing of the pods and the box the prefabricated parts are not included with the exception of the compression springs, which were slightly simplified.

Part number	Sub-assembly	Part name	Quantity	Material	DImension
1	Pod	Wooden disk	4	Multiplex wood	6 mm thick
2		Steel disk	4	Steel plate	0,5 mm thick
P1		Compression spring	4	Spring steel	1 mm wire thickness
P2		Bolt	4		M4
P3		Nut	4		M4
3	Box	Steel shaft	4	Steel tube	15 mm outer diameter
4		Top panel	1	Multiplex wood	18 mm thick
5		Side panel	2	Multiplex wood	9 mm thick
6		Bottom panel	1	Multiplex wood	6 mm thick
P4	Pods and box	Split pin	4		1,8 mm diam-eter
7	Button inter-face	Buttons front panel	1	foam board	5 mm thick
8		Buttons side panel	2	foam board	5 mm thick

Table 4.1 *Pods, box and button interface parts*

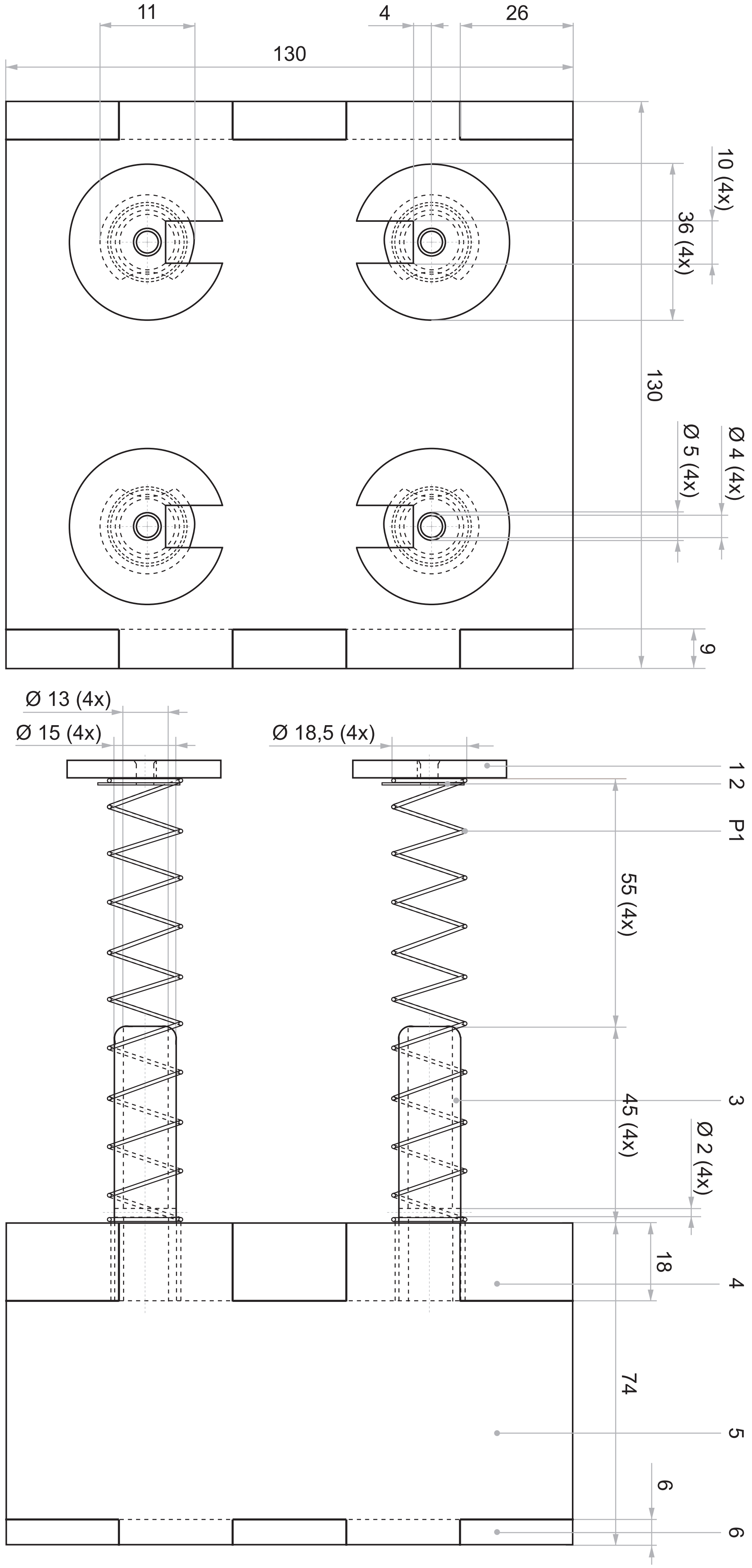
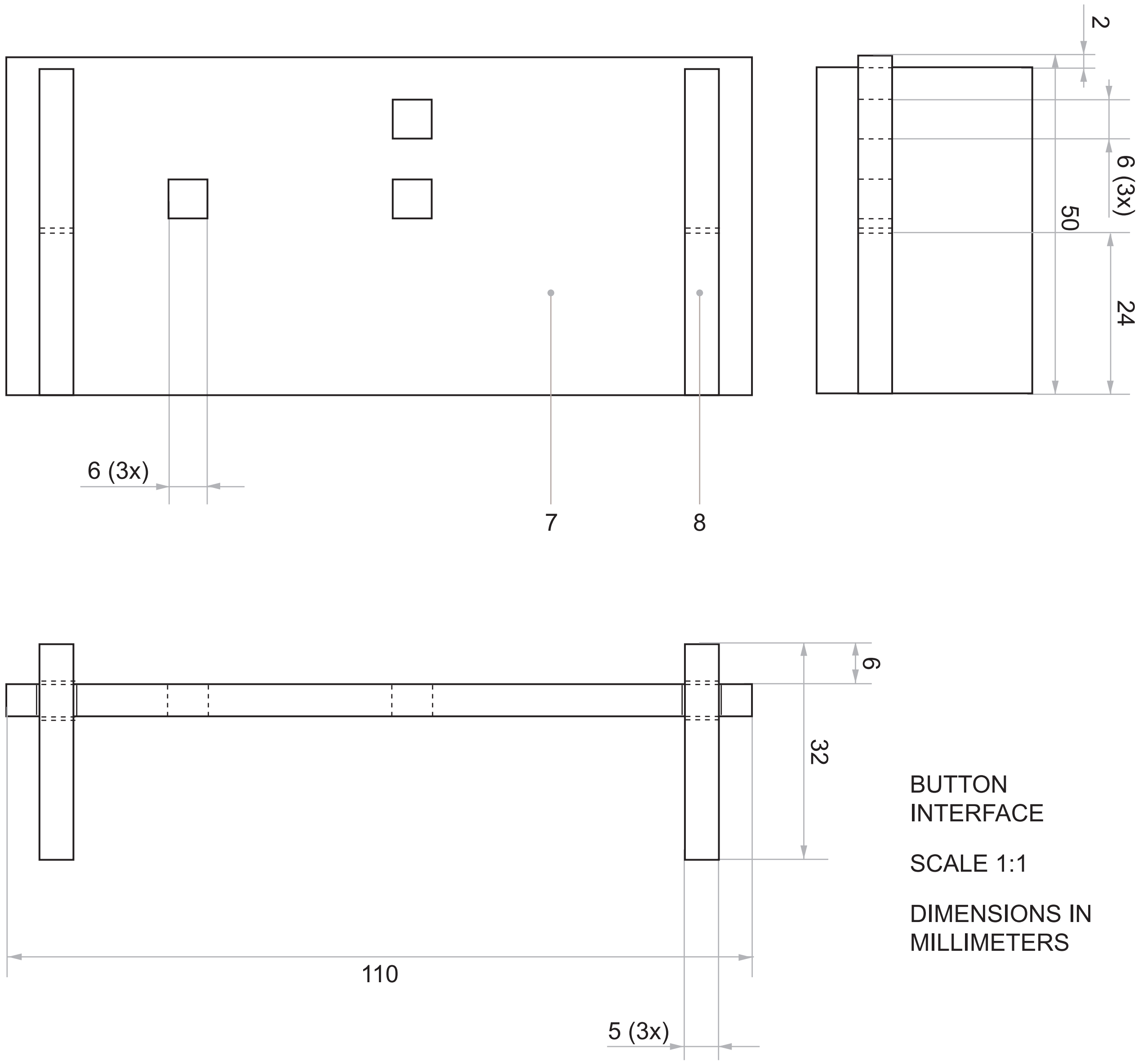


Figure 4.12 *Assembly dimensional drawing*

ASSEMBLY
PODS AND BOX

SCALE 3:4

DIMENSIONS IN
MILLIMETERS



BUTTON
INTERFACE

SCALE 1:1

DIMENSIONS IN
MILLIMETERS

Figure 4.13 *Button interface dimensional drawing*

4. Making the prototype

In the following the process of making the prototype is described as well as the reasons for choosing certain production methods.

Mechanical parts

The four walls of the wooden box are laser-cut from multiplex sheets of different thicknesses and then glued together overnight using wood glue. Using the laser cutting technique it is relatively easy to cut teeth-like notches into the wooden walls. The teeth make it easier to line up the walls to form a square (looking from the side) and increase contact surface allow for a connection with the glue. The holes in the box that the steel shafts are glued in are also laser-cut.
The shaft that were glued into the holes in de wooden box with epoxy glue are made from a steel tube. The steel tube already had the desired outer and inner diameter and only had to be cut to the right length and rounded off at the top. The rounding was done by hand with a sanding machine. There is also a small hole in each of the shafts for the split pens to go through. The holes were drilled with a 2 mm drill. The split pens, extension and compression springs are prefabricated parts (see figures 4.15|2, 4.14|1 and 4.12|3). The wooden disks (4.14|3) that hold the sensors and the small steel disks (4.14|2) that are used to attach the wooden disk to the springs are all laser-cut. Due to their round geometry with holes and indentations laser cutting is a very suited production process. It makes it possible to make the wooden and steel disks very precisely in one production step. The steel disks are attached to the wooden disks with nuts and bolts. The top end of the spring is hemmed in between the steel and wooden disk. The holes in the

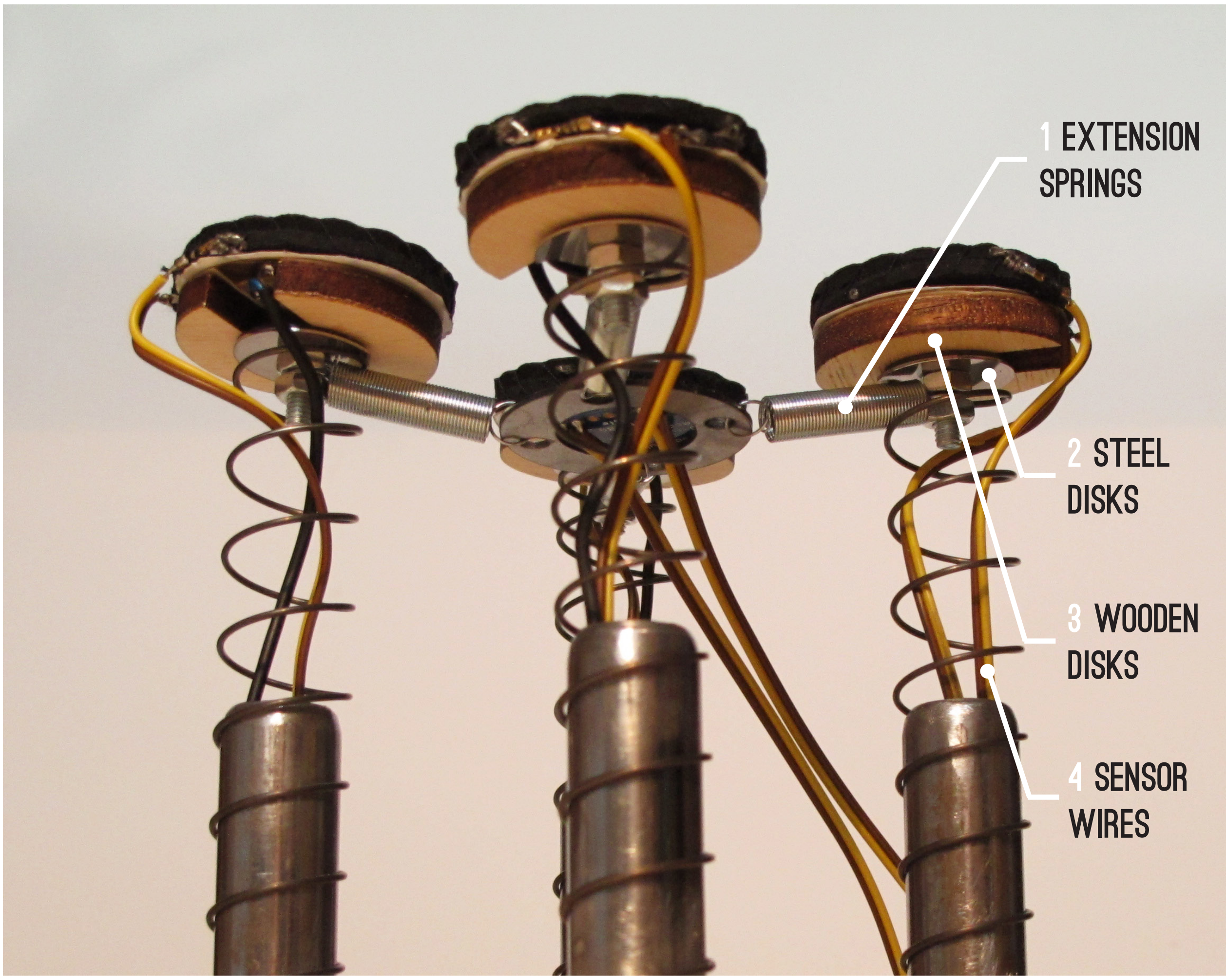


Figure 4.14 *Fully assembled mechanical prototype*

wooden disks are finished with a countersink to sink the top of the bolts into the disks. The steel ring (4.15|1) that the accelerometer is attached to is also laser-cut. It was re-used from the mechanical prototype.

Sensors

The prototype has three types of sensors: four pressure sensors, four piezos and an accelerometer. The latter two are prefabricated while the former were hand-made for the prototype. The pressure sensors (see figure 4.16) are made from are made from two layers of neoprene sheet (4.16|1) with three layers of velostat (Adafruit 1361; 4.16|2) in between. The neoprene was cut into rounds with the same diameter as the wooden disks and the circuit was sewed into the neoprene with conductive thread (4.16|3). The thread was sewed in a line across one side of the neoprene round and then two rounds are placed on top each with the threads facing each other but rotated through 90° so that the threads form a cross and intersect in the middle. Then the three layers of velostat were put in between the two rounds and they were sewed together with (non-conductive) thread. After repeating this for every sensor the ends of the conductive threads were used to sew wires (4.16|4) to the sensor in order to connect it to the circuit.

The piezos (Murata 7BB-35-3) are relatively thick (0,53 mm) and wide (diameter: 35 mm). The bigger the diameter of the piezo, the more sensitive the piezos are to vibrations. Two wires (4.14|4) had to be soldered onto each piezo, one onto the metal disk and one onto the piezoelectric material in the middle of the disk. The piezos are taped with double sided tape onto the wooden disks and the pressure sensor are taped on top of the piezos. The Adafruit MMA8451triple-axis accelerometer was selected, because of its relatively high precision (14 bit, meaning the tilt is measured in 16384 distinct values) and low cost.

Button interface

The three parts that make up the panel that holds the buttons were cut from foam board. They are designed so they could be connected by simply sliding them into each other. The foam board is very for this design because it can be pressed together from the side to make a relatively stable press fit connection and it is also

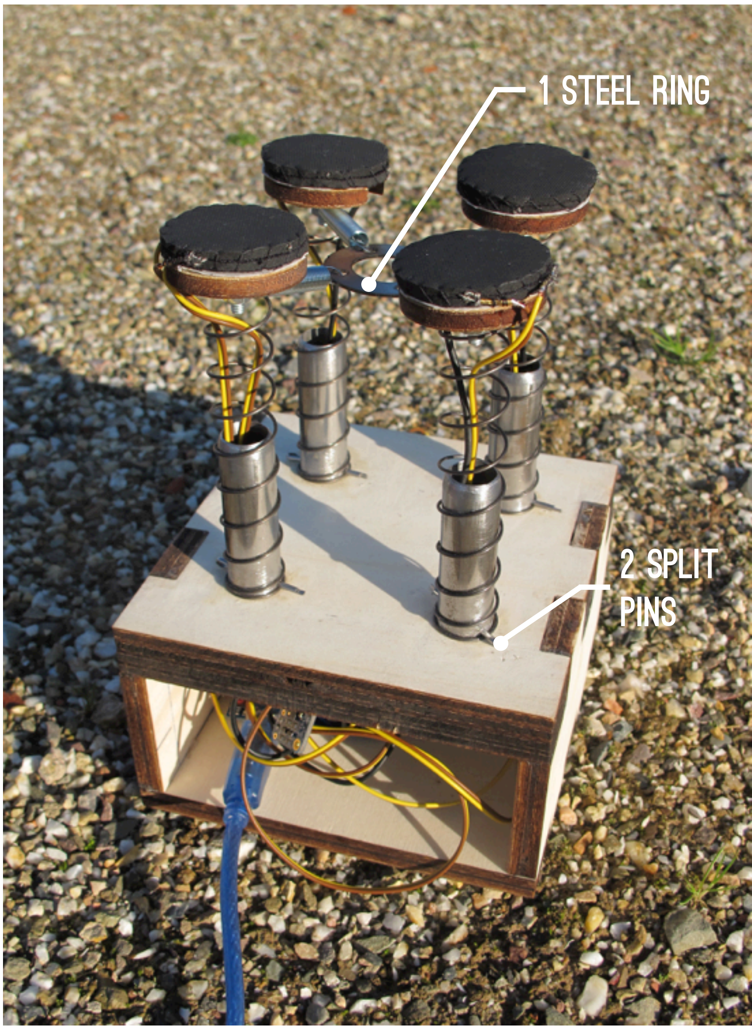


Figure 4.15 *Prototype with cable*

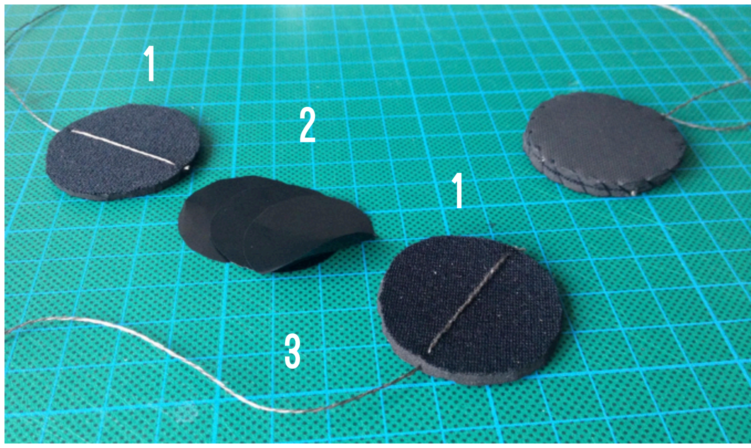


Figure 4.16 *Layers of the pressure sensors*

relatively stiff and its surface does not easily deform. However, some cyanoacrylate glue was added to make the connection more durable. Small holes were cut into the front panel that the buttons and the LED were inserted into. They were also fixated with cyanoacrylate glue and soldered to the circuit afterwards. Lastly, a small piece of masking tape was added next to each button with the name of the button on it.

Electronic circuit

The electronic circuit (see figures 4.17-19 and 4.22) was soldered to two prototyping shields (protoshields) after testing on a breadboard. The protoshield (see figure 4.21) can simply be inserted into the connectors of the Arduino (see figure 4.20). The sensors and buttons are connected to the proto shield with screw terminal blocks (4.21) so that they can easily be detached and the circuit can be taken out. Just like in the second sensor test all the piezos and pressure sensors are paired with a resistor (4.22|R1-R8) with a resistance approximately equal to the maximum resistance of the sensor. The piezos are paired with 1 MOhm resistors and the pressure sensors with 20 KOhm resistors. The pressure sensors (4.22|U2-U5) and piezos (4.22|U7-U10) are all connected to an input voltage of 5 V and to the ground. The analog pins are connected between the respective resistor and sensor. The accelerometer (4.22|U11) does not need to be paired with a resistor since it is embedded on a breakout board. It is connected to the 5 V and ground pin and two of the analog pins (4.22|A4 and A5) on the Arduino.

The piezos, accelrometer and pressure sensors all need to be connected to an analog pin. Because the Arduino only has six analog pins, a 16-channel multiplexer (MUX) was used to expand the number of analog pins. The 16-channel MUX (4.22|U6) that was used (SparkFun CD74HC4067) is connected to one analog and 4 digital pins on the Arduino and provides 16 pins that be used as either digital or analog pins. The piezos are connected to four of the pins on the MUX. Of course, the MUX can only send one signal at a time to the analog pin on the Arduino. This means that it has to be programmed so that it constantly loops through the four pins that the piezos are connected to. This process makes reading the values from sensors connected to a multiplexer slower than with a direct connection. That can have the effect that some short and sudden changes in value are not detected.

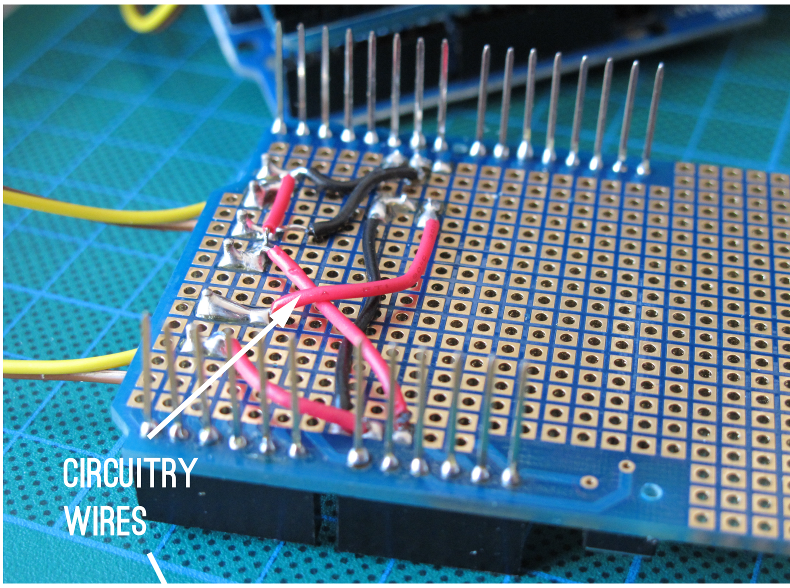


Figure 4.17 *Electronic circuit buttons and LED*

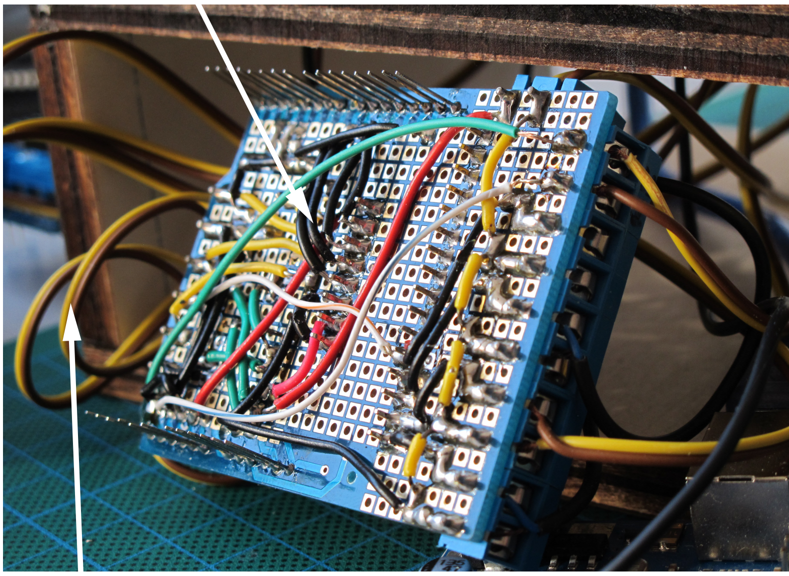


Figure 4.18 *Electronic circuit (bottom view)*

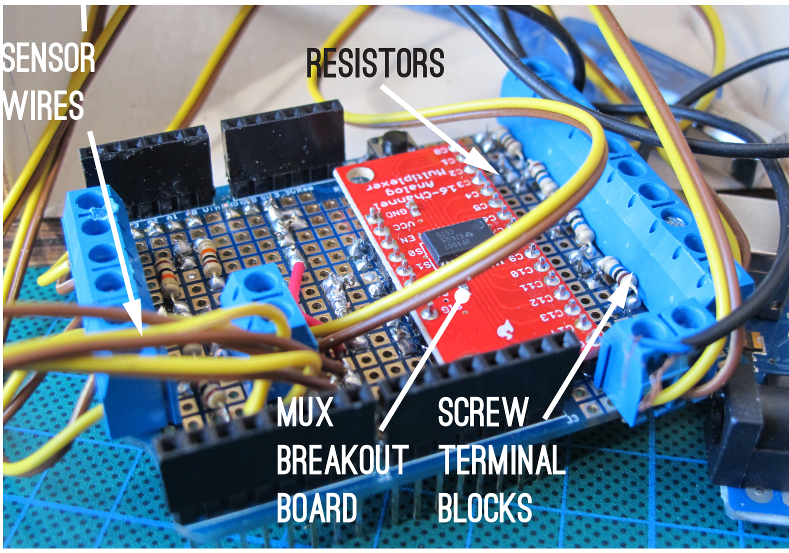


Figure 4.19 *Electronic circuit (top view)*

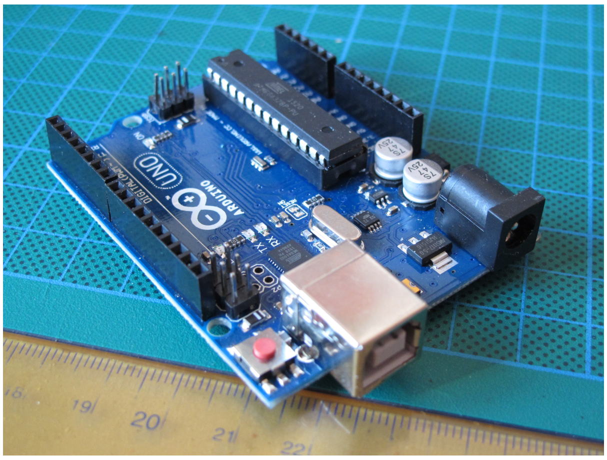


Figure 4.20 *Arduino UNO r3*

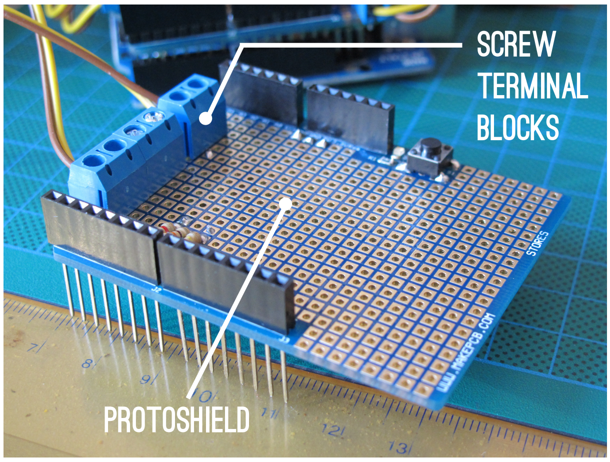


Figure 4.21 *Protoshield and screw terminal blocks*

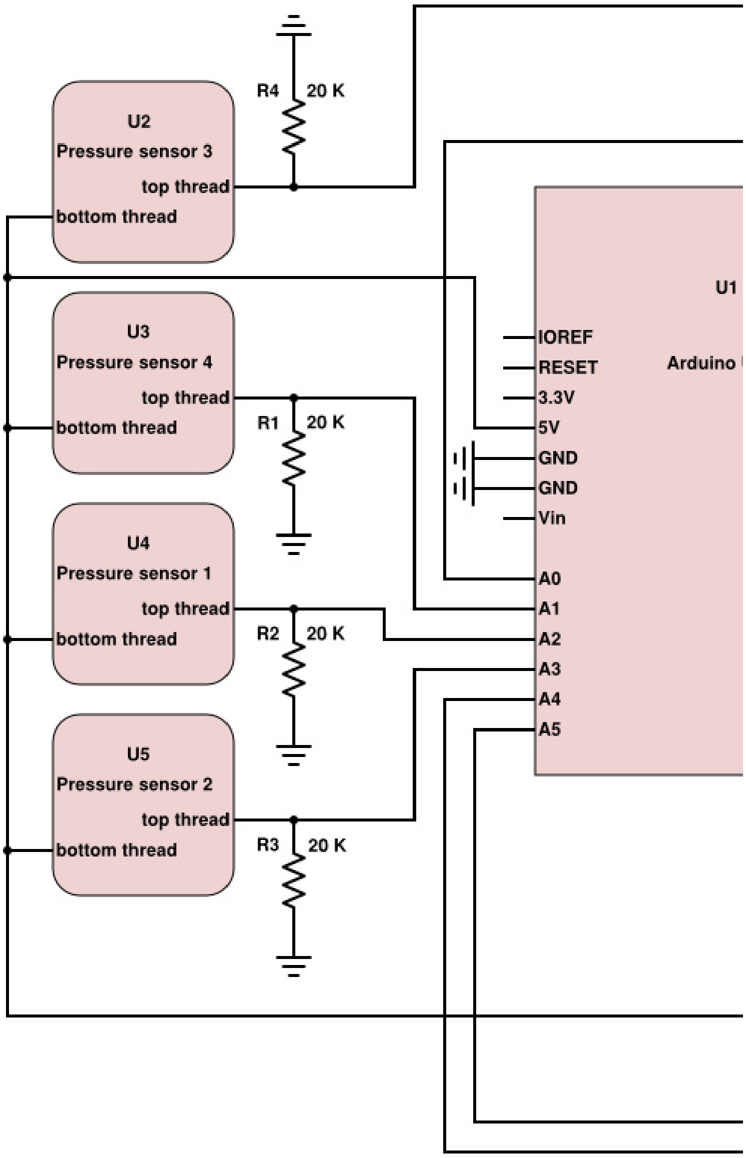
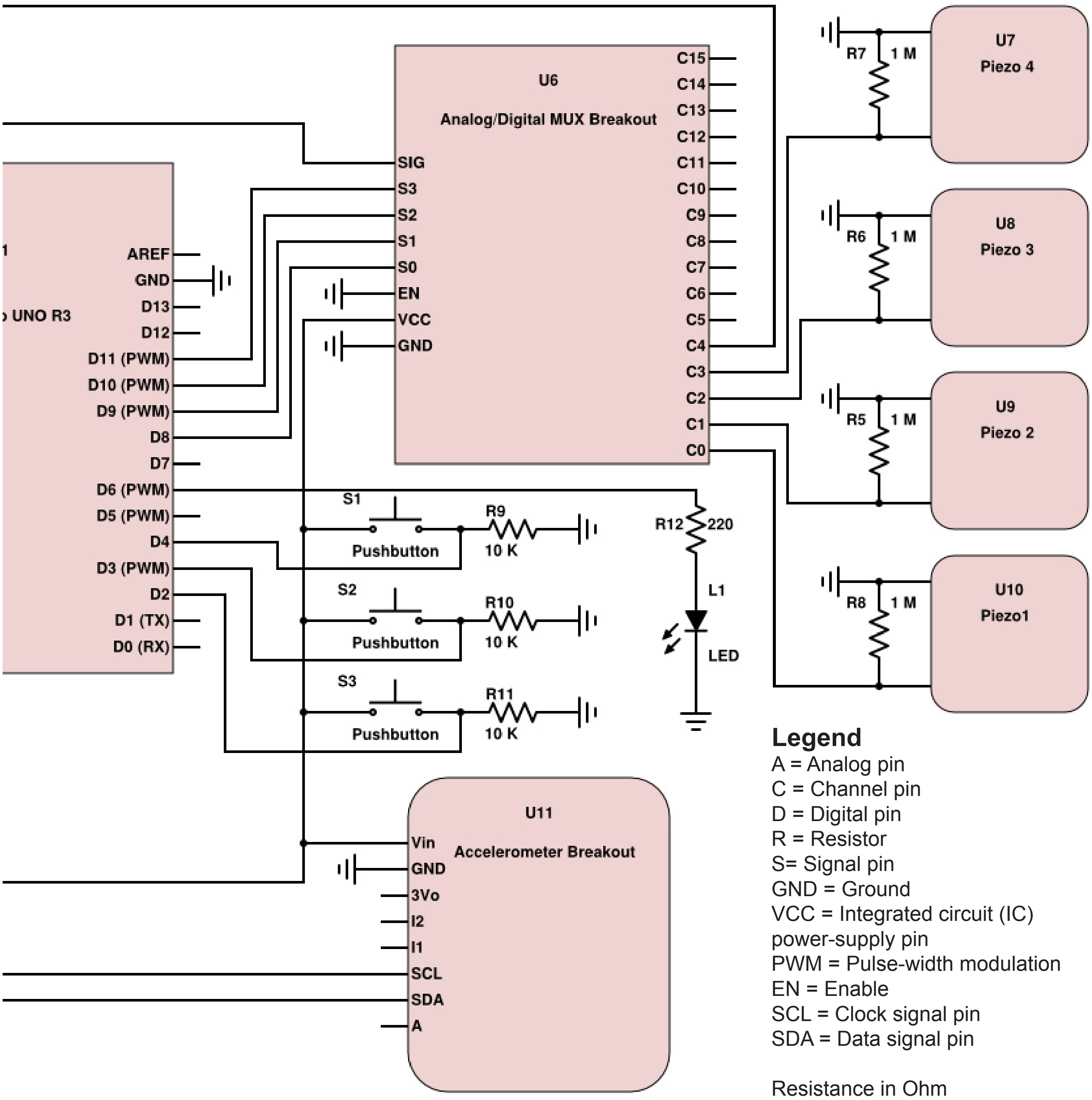


Figure 4.22 *Electronic circuit prototype schematic*



Legend

A = Analog pin
C = Channel pin
D = Digital pin
R = Resistor
S= Signal pin
GND = Ground
VCC = Integrated circuit (IC) power-supply pin
PWM = Pulse-width modulation
EN = Enable
SCL = Clock signal pin
SDA = Data signal pin

Resistance in Ohm

5. Arduino software

To read the data from the sensors and use it to synthesize sounds a program was written in the Arduino IDE (see figure 4.23). This program is uploaded from a computer to the Arduino board via USB. In general the program reads all the values from the sensors and converts them into a MIDI signal that is then sent via USB to the computer. On the computer the data can be accessed and sent to a MIDI channel with a bridge program like e.g. Hairless MIDI to Serial bridge. These MIDI channels are managed by a driver (IAC driver on Mac) and allow for data to be sent between applications on a computer. This way the signals can be sent to any music program that supports MIDI and used to play music.
In the following section the functionality of the program-code will be explained, divided into how the signal from each of the sensors is processed.

Piezos and pressure sensors

Since the piezos are connected to the MUX their values have to be read with the readMux function. To do so there is also a function (for-loop) that loops through all the sensors that are connected to the MUX and stores their values with the corresponding sensor pin so they can be read with the readMux function. After that the values from the pressure sensors are read with the analogRead function except for the one pressure sensor that is also connected to the MUX. There is an if-function for each of the piezos that is called if the value from the piezo is above the threshold, which was set to 80. In the if-function the value from the pressure senor that is on the same pod as the piezo is mapped to a MIDI value that corresponds with a note from the musical scale in the octaves 0-5. So each pod has its own specific note that shifts in octave depending on how much the pressure sensor is pressed down. The values are mapped to musical notes using a simple mathematical function. The chosen number of octaves can be extended (up to 11) and the specific note that each pod plays (D, E, F# and G#) can also be changed, although these functions are not integrated into the interface. The measured value from the piezo is then mapped to the velocity of the MIDI note. This means that the loudness of the played note depends on how fast the user touches the pod with his finger. The note is sent using the sendNoteOn function and then stopped with the sendNoteOff function. The length of the delay between sending the note and stopping it also depends on the vibration measured with the piezo. Both functions for sending the MIDI note are from the Arduino MIDI Library (http://arduinomidilib.fortyseveneffects.com). Some lines of code that are repeatedly used are turned into functions that be called on for each individual piezo.

Accelerometer

The Adafruit MMA8451 accelerometer comes with a library that provides a function (mma.read) for reading the measured rotation. This function returns the rotation of the accelerometer around its X-, Y- and Z-axis in 14-bit. Then an if-function is called for each of the three values. In the function each of the values is mapped from 14-bit (16.384 discrete values) to 7-bit (128 discrete values), because MIDI data can contain maximum 7-bit. Next the value is sent function to the music program using a MIDI.sendNoteOn function. The values are sent via a specific MIDI channel for each axis so that they can be used to control different properties of the electronic instrument.

Buttons

To determine whether one of the buttons is pressed two variables are used that store the current and the last state of the button. The current states are constantly updated and stored in one variable for each of the five buttons. For every button there is also an if-function that is called when the current state is 'pressed' and the last state is 'not pressed', meaning that the button has just been pressed. When this happens a MIDI note is sent. With this function the Arduino only sends a 'NoteOn' when the button has first been pressed and does not constantly send MIDI messages as long as the button is pressed. Another function is called when the current state is 'unpressed' and the last state 'pressed', meaning that the button has just been released. This function turns off the MIDI note once when the user releases his/her finger from the button and not constantly after the release. After checking whether the button has just been pressed or released the current value becomes the last value.

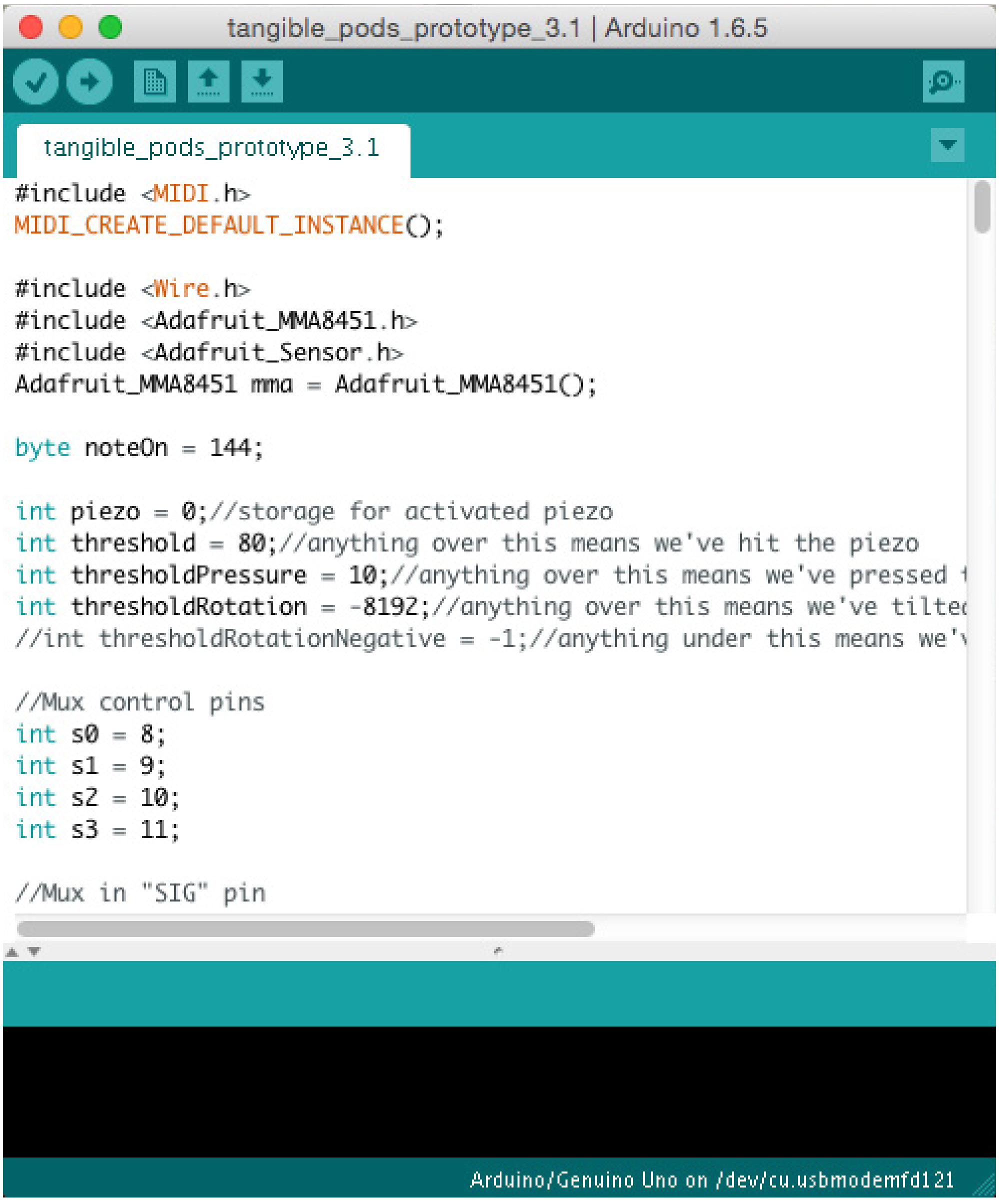


Figure 4.23 *Arduino program version 3.1* (The full code can be seen in appendix 4)

6. Usability test

Research questions

1. How do people with ASD perceive the usability of the prototype?
2. How do users without a cognitive impairment perceive the usability of the prototype?
3. Is the perceived usability influenced by the addition of the looping function?

The purpose of the research is to test the usability of the prototype with users with or without ASD and to determine what can be changed about the prototype or the concept to improve it. The test is based on the System Usability Scale (SUS) developed by Brooke (1996). Brooke defines usability as an artifact's appropriateness to a purpose in terms of effectiveness, efficiency and satisfaction [44]. In the context of this assignment the SUS is used to indicate whether users can quickly learn how to use the prototype and whether they enjoy using the prototype. Furthermore the purpose of the research is to indicate whether there is a difference between the perceived usability by people with and without ASD.

Setup

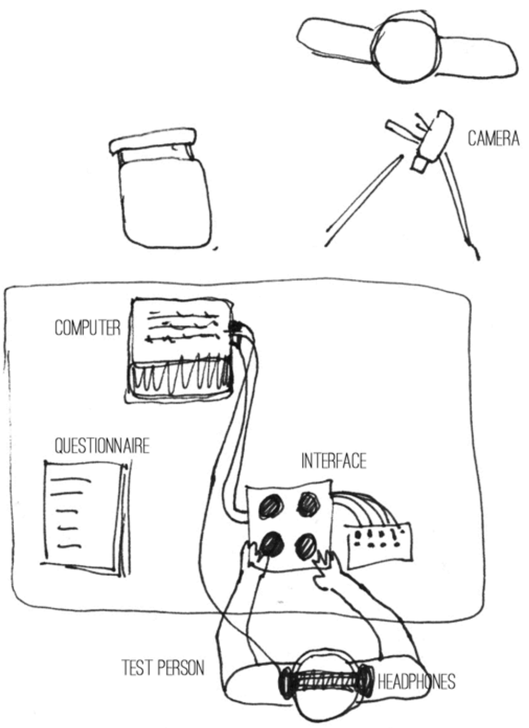


Figure 4.24 *Usability test setup*

Participants

People of any age and gender are allowed to participate. The intended male/female division within the group of participants is 50/50. Furthermore the intended percentage of participants with ASD is 50%.

Procedure

During the usability test, participants are first asked to state or fill out their age and gender. After that, they are asked to put on headphones play with the prototype by touching the interface and make sounds for approximately two minutes. After this they are asked to answer or fill out questions (see appendix 8) regarding using the interface like "did you find it difficult to use this interface? Then more information on how to use the interface and specifically the loop function is given and the participant is asked again to play with it for approximately 2 minutes. After this the participant is asked to fill in the similar questions to the ones before and at the end there are two open questions the participant can answer (see appendix 8). During the two 2-minute tests of the interface, participants are being filmed with a video camera. The difference between the first and second test is that only in the second test the looping function has been introduced to the participants to determine whether this has an influence on the usability.

Evaluation

SUS is used to determine the degree of agreement or disagreement with a statement30. The researcher then looks for general agreements or disagreements with certain statements in a group of participants. Furthermore, a usability score is calculated from each participant's answers to the questions based on the SUS. Answers to the open questions are used to determine possible improvements on the design.

Results (n=13)

In the following the results from the four pages of the test questionnaire will be laid out. Furthermore, the difference between participants with and without a cognitive disability is laid out. Additional to the responses from the test questionnaire notable things the participants said during the test were also taken into account. During the tests it quickly became clear that some participants expressed reactions that they did not write down in the questionnaire, probably because writing costs more effort than saying something. These remarks were written down by the researcher.

Participants

13 people took part in the usability test. They are all between 20 and 34 years old and the average age of participants is ca. 24. Six participants have a cognitive disability on the autism spectrum. One of the participants with autism also has Attention Deficit Hyperactivity Disorder (ADHD). Two of the thirteen participants are female and eleven are male. All of the participants with ASD are male. Five participants said they had no experience with making music, three said they had some and five said they had a lot of experience. No professional musicians participated. All the data that was collected from the participants is shown in table A.3 (A) in appendix 8.

SUS 1

After using the prototype for the first time the participants were asked to fill out a SUS form (see appendix 7). In this form they are given ten statements about the prototype to which they can respond on a scale of one to five from strong disagreement to strong agreement. The results are shown in table A.3 (B) in appendix 8. The questions are formulated so that responding with agreement is a positive judgment about the prototype in some questions but a negative judgment in other. The responses that express a positive judgment about the prototype are highlighted green while responses that express a negative judgment are highlighted red. Some participants did not know how to respond to some statements. This is represented with a question mark that is highlighted yellow. None of the statements elicited a uniform response in agreement or disagreement. However, five of the statements elicited a more positive judgment on average and three of those five only received neutral or positive judgments. None of the participants thought that the interface is unnecessarily complicated and none of the participants disagreed with the statement that the prototype was easy to use. Furthermore, none of the participants disagreed with the statement that most people would learn to use the interface quickly. Most of the participants disagreed with the statements that they found the interface cumbersome to use and that they would need assistance from a technical person to use it properly. The average response of the participants with a cognitive disability was also compared to the average response of the people without a cognitive disability. Overall only small differences were found. For example, all of the people with a cognitive disability disagreed with the statement that they would need assistance from a technical person to use it properly while some of the participants without a cognitive disability did not. The SUS score was calculated for each participant from the answers that the participants gave. Every answer was translated to a scale from 0 to 4 and the answers to the negative statements about the interface (statement 2, 4, 6, 8 and 10) were inverted. Then all the values were added up and multiplied by 2,5 to get a total score on the scale of 0 to 100. The prototype received an average score of ca. 66,7 after using it for the first time with scores ranging from 40 to 80.

SUS 2

Before filling out the second SUS form users were given a short instruction on how to use the looping-function of the prototype and were given some time to try it out. The results from the second SUS form are also presented in table A.3 (C). The second form is almost the same as the first with the exception of a small change in statement 5. As in the first form, the statements in the second form did not elicit uniform agreement. This time, however, eight of the statements received more positive judgments about the prototype of which one received no negative judgment at all. Again, no participant disagreed

Theme	Sub-theme	Positive experience	Negative experience	Observation	Total
Pods	Sensitivity		3	1	4
	Number of pods		1		1
Erase'- and 'undo'-button	Undo erases everything		2		2
	Undo stops loop		1		1
Audio feed-back	Delay		2		2
	Consistency		3		3
	Precision		1		1
Loop function	Display and changing loop length		3		3
	Loop volume		1		1
	Keeping rhythm		1		1
	Manipulating sounds in hte loop		1		1
	Missing play/ pause button		1		1
Sounds	Variety		4		4
	Differentiation		2		2
Visual appear-ance	Colors		1		1
Usability			2		2
General reac-tion	Mechanical parts	1	1		2
	Emotional reaction	4			4
	Purpose			2	2
	Unusualness			4	4

Table 4.2 *Themes and sub-themes*

that most people would learn to use the interface quickly. Also most of the participants disagreed that the interface is unnecessarily complicated or that they would need assistance from a technical person or that it is too inconsistent or cumbersome to use. Most of the participants agreed that using the interface was easy and felt confidant using it.

The average SUS score from the second form was 69,8, a little higher than the first one. Scores ranged from 32,5 to 88. Again there were overall no big differences between participants with and without a cognitive disability, even though in the second SUS form the differences are bigger than in the first form. The difference in average SUS score was approximately 9,7, while in the first form it was approximately 3,7. The second SUS scores are not consistently higher than the scores after first use (table A.3|D).

Open questions and notable expressions
All of the answers to the two open questions can be seen in table A.4 (A) in appendix 8 as well as the remarks that were written down (B). To analyze both the written and the spoken reactions they were categorized into themes depending on what the reaction referred to (see table A.5 in appendix 8). After that, reactions were further sorted into sub-themes and an overview was made of the amount of positive and negative reactions and observations regarding these sub-themes (see table 4.2). This was done to figure out if there is agreement in opinions about certain aspects of the user experience. The most agreed upon shortcomings were that the prototype should offer a bigger variety of sounds to play with, that the pods should be more sensible, that the audio feedback should be more consistent, that the length of the loop should be displayed and that users should be able to change the loop length. Furthermore, four people expressed that they liked the interface and four people made a remark about the unusualness of the design.

The video footage from the tests is attached in appendix 9 (on a DVD).

Concluisons

No general conclusions can be made based on the data from the usability test. To do that the sample size is too small. Furthermore the results might be biased due to the unequal male/female ratio. Cultural background was also not taken into account. The results suggest that most participants found the prototype to be relatively usable seeing as there is no general agreement on any negative statement about it. They also suggest that there is room for improvement, because the responses could have been more positive and many complaints and suggestions were made in response to the open questions. There was no notable difference in perceived usability between users with and without cognitive disabilities. Additionally, no notable difference in usability between using the interface with and without the loop function was perceived, although this could be due to the shortcomings of the button interface and not the function itself. To be able to make a conclusion more research needs to be done.

The results from the answers open questions and other reactions did however result in a list of issues that can be improved to possibly enhance the usability of the TUI:

- Sensibility of the pods
- Erasing sounds from the loop
- Delay between interaction and feedback
- Consistency in feedback
- Displaying the loop length and allowing for it to be changed
- Offering a bigger variety of sounds
- Offering more distinct sounds per pod

5. Evaluation

For this bachelor assignment a TUI for audio and haptic feedback was developed. Furthermore, a working prototype was made and tested with users. The interface is based on a vision of integration that supports embodied thinking processes. In the beginning of the assignment a hypothesis was made that the interface supports meta-cognitive skillfulness and deficiencies for people with cognitive disabilities. Testing this was not possible within the scope of the assignment, because it would require a large and diverse group of people with and without cognitive disabilities. However, a smaller test was executed to test the usability of the interface with people with and without ASD. The results from the test cannot be generalized, but they do give the indication that there is no significant difference in the perceived usability of people with ASD compared to people with no cognitive disability.

The prototype allows users to make sounds by physically interacting with it. Users can also record sounds and repeat them in a loop. The prototype allows for a high degree of freedom in manipulation. Furthermore, the prototype supports haptic feedback with the use of compression springs (see figure 4.8|3). All of this is achieved with relatively low-cost technology. Most participants in the usability test agreed that the interface is not very complicated, not difficult to use and does not require much time to learn how to use it. This suggests that the interface is relatively successful in supporting simple, immediate interaction and has a relatively low learning threshold. However, not all responses were positive and many suggestions were made about how it could be improved. The complaint that was raised the most was that users are not given enough different sounds to play with. This is something that was part of the concept and is possible with the prototype. The data can be mapped to any sound in the music software, but this function is not integrated into the interface itself and has to be done on the computer. The ability to explore, iterate and express oneself using the interface is hindered by the relative difficulty of mapping different sounds to the input data. Furthermore, many participants wanted the interface to be more sensitive to physical input and give them more control over the resulting output. Another frequent suggestion about the loop function is that it should be possible to see the length of the loop and change it. The loop function adds an extra affordance and challenge to the interface, but its usability could be improved by redesigning the button interface which controls it.

The prototype establishes a hybrid link between physical form and digital audio synthesis. It is focused on audio feedback instead of a combination of audio and visual feedback. Adding 2-D or 3-D visuals might improve its usability, because it would offer the user a wider range of affordances. The direct translation of the physical input data and the use of low-cost technology results in a perceived randomness and ambiguity. Some participants in the test expressed frustration with this but some were also eventually pleased with the resulting sounds ("It is weird at first en then you get what you could do with it"[table A.4|B]). Users were probably frustrated because the interface did not give them a sense of being in full control.

In conclusion, the feasibility of the concept has been shown and the envisioned tangible interaction was realised for audio feedback with the prototype. The prototype does not meet all the requirements and wishes but shows some of the possibilities of the Tangible Pods concept. The usability test suggested that the prototype is not difficult to use and brought to light a number of factors that could further improve usablility. Overall it can be said that Tangible Pods allows users to spontaneously play with digital sounds, supports hybrid tangible interaction and haptic feedback and fosters embodied thinking processes.

6. Conclusion and future work

Concluison

For this assignment a novel interface for hybrid tangible interaction was developed. I started with only the experience from the Free Assignment, an affinity for sounds and music and an interest in Human-computer interaction (HCI) and VEs for the cognitively impaired. From there, a literature research was done on the theory behind RST, other related work and VEs for people with ASD, specifically interaction based on the theory of embodied cognition. Based on the research requirements, wishes and the vision for the interaction that the interface should facilitate were developed. Meanwhile, iterations were made based on the vision , a process which eventually culminated into three concepts . The Tangible Pods concept was chosen for further development. Multiple sensors and an Arduino were used to realise the concept. These sensors were tested in simple set-ups and the design of the interface was defined in more detail before the prototype was made. The usability of prototype was tested with six people with ASD and seven people without ASD. Finally the usability test and the final result were evaluated. The participants learned how to use the prototype quickly and most were positive about the experience, although there is room for improvement in usability. The strong point of the prototype is that it can be immediately used, provides freedom in physical manipulation and haptic feedback. Tangible Pods allows users to spontaneously play with digital sounds, supports hybrid tangible interaction and haptic feedback and fosters embodied thinking processes. This assignment is a step in a long process aimed at developing interfaces that support humans in achieving their goals by making use of their capacities and integrating the virtual into the natural environment.

Future work

In this assignment the Tangible Pods concept was developed and its feasibility was shown with a working prototype. The possibilities of the concept and prototype were described and demonstrated. The prototype is not, however, a full realization of the envisioned interaction. The vision and study that went into developing and the the testing results should be used as a basis for further development of the interface. The interaction of people with cognitive disabilities with VEs needs to be further studied and new ways of implementing the theoretical background need to be developed and tested. This assignment is a step in a long process of developing interfaces that support humans in achieving their goals by making use of their capacities.

Possible steps in further development of Tangible Pods are adding three-dimensional visual feedback, improving on the current functions of the prototype, better supporting two-handed interaction and allowing for multiple users to use the interface at the same time. The interface could also be adapted for other interactions like for example interaction using one's feet. After having developed a new version of the interface, a study on its influence on meta-cognitive skillfulness can be done.

7. References

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Appendix

1. Music therapy mails

Anneke Groot (Horison)

Original message sent via the Horison website (http://www.horison.nl/contact/) on 22.09.2015
Hallo,
ik ben student aan de Universiteit Twente en ik ben bezig met het ontwikkelen van een interactief muziekspel. Dit spel moet het mogelijk maken voor meerdere mensen om met elkaar muziek te maken met fysieke objecten zoals lego-speelgoed die door de toevoeging van technologie geluiden maken.
Het spel moet zo cognitieve processen stimuleren (verwerken van auditieve, visuele en haptische prikkels) op een gecontroleerde manier. Het doel ervan is om het zo te ontwerpen dat het ook (of juist) voor kinderen met autisme geschikt is. Nu ben ik nog in het begin van de ontwikkelingsfase van het project en ik was benieuwd of u nog tips heeft over het spelen met kinderen met autisme.
Zijn er dingen die goed werken of juist niet?
Wat voor speelgoed en materialen zijn goed geschickt om mee te spelen (zoals die die het kind al kent)?

Met vriendelijke groeten,
Peter Schaefer

Reply from Anneke Groot on 22.09.2015
Hallo Peter
Vanuit ons perspectief is vooral de manier waarop je speelt met een kind van belang.
Maar muziek heeft een bijzondere uitwerking op kinderen en het lijkt me heel bijzonder als dat zo toegankelijk is als bv met de lego tijdens spel.
Wat goed werkt in het spelen is om in eerste instantie af te stemmen op het kind en een kind te volgen. Als je merkt dat er meer contact is, kun je dingen toevoegen.
Ik stuur je wat informatie mee. Het is een beetje verouderd en we zijn bezig met een nieuwe versie, maar de benadering verandert niet.
Mocht je concrete vragen hebben, laat het me gerust weten,
heel veel succes en plezier met je project
en we zullen er in de toekomst dan zeker iets over horen,
hartelijke groet
Anneke

Nadine Spigt

Original message sent via the ambiq website (https://www.ambiq.nl/contact/contactformulier) on 02.10.2015
Hallo,
ik ben student aan de Universiteit Twente en ik ben bezig met het ontwikkelen van een interactief muziekspel. Dit spel moet het mogelijk maken voor meerdere mensen om met elkaar muziek te maken met fysieke objecten zoals lego-speelgoed die door de toevoeging van technologie geluiden maken.
Het spel moet zo cognitieve processen stimuleren (verwerken van auditieve, visuele en haptische prikkels) op een gecontroleerde manier. Het doel ervan is om het zo te ontwerpen dat het ook (of juist) voor kinderen met autisme geschikt is. Nu ben ik nog in het begin van de ontwikkelingsfase van het project en ik was benieuwd of u nog tips heeft over het spelen met kinderen met autisme vooral in de context van muziektherapie.
Hoe gaan kinderen met instrumenten om? Welke instrumenten werken goed voor de meeste kinderen? Heeft u hier ervaring mee of kunt u me doorverwijzen naar iemand die muziektherapie doet?

Met vriendelijke groeten,
Peter Schaefer

Reply from Nadine Spigt on 23.10.2015
Dag peter,

Ik kreeg een mail van je doorgestuurd mbt je onderzoek. Ik ben muziektherapeute en heb veel met kinderen met autisme gewerkt, o.a. voor stichting papageno.
Als je iets specifiekere vragen hebt, dan kan ik daar zeker antwoord op geven. Ik zou je vraag ook aan stichting papageno sturen en vragen het in hun muziektherapeuten netwerk te verzenden, dan heb je direct de meest actieve muziektherapeuten die werken met autistische kinderen te pakken.

Laat me even weten wat precies je vraag is, evt belafspraak maken kan ook.

Met vriendelijke groet, Nadine Spigt muziektherapeut

Second message sent on 27.10.2015
Dag Nadine,

bedankt voor de reactie. Ik benvooral ben ik heel benieuwd hoe muziektherapie precies werkt. Dus waar vindt het plaats, wat voor instrumenten woorden daarbij gebruikt , wat doen jullie dan samen met de kinderen en wat is het doel ervan? Verder zou het natuurlijk heel leuk interessant om een therapiesessie mee te maken, maar een belafspraak zou ook heel nuttig zijn.
Hier nog een keer mijn vragen:

- In wat voor een omgeving vinden de therapiesessies plaats?
- Doet uw dit individueel of in groepen of allebei?
- Wat voor oefeningen doet uw met de kinderen/cliënten (en verschilt dit per leeftijd en aandoening)?
- Welke instrumenten/voorwerpen gebruikt uw hierbei?
- Wat voor vaardigheden oefent uw met de kinderen/cliënten?
- Wat is het doel van de therapie?
- In hoeverre verschilt de reactie van de kinderen/cliënten?

Ik heb niet perse een antwoord op alle vragen nodig, maar ik wil vooral meer weten over muziektherapie met de achtergrond van het ontwerpen van (hybriede) instrumenten voor dit soort toepassingen. Als jij mij daarmee verder kan helpen zou dat echt tof zijn.

Met vriendelijke groeten,
Peter

Second reply from Nadine Spigt on 03.11.2015
Hai peter,

Ik zou deze vragen zeker ook naar stichting papageno sturen zodat je een diverser beeld kunt krijgen van muziektherapie met autistische kinderen.
Er zijn vast een aantal therapeuten die antwoord kunnen geven

- In wat voor een omgeving vinden de therapiesessies plaats?

Ik heb regelmatig therapie gegeven in de meest vertrouwde omgeving voor een client: thuis. Dit is minder belastend voor ouders (hoeven niet eweer op en neer te rijden etc) en client voelt zich daar het meest veilig dus komt het gemakkelijkst tot contact en vertrouwen. Hoeft oeverigens lang niet altijd het geval te zijn, soms past 'therapie' helemaal niet in het rijtje thuis van waaraan ze gewend zijn wat ze thuis doen, en lukt therapie dus helemaal niet daar, omdat het niet strookt met hun dagelijkse structuur. Kan dus ook op school zijn of in een therapie lokaal. Afhankelijk van wens client, ouders/verzorgers en mogelijkheden therapeut dus.
Thuis of op andere locatie neem ik instrumenten mee daarheen, in mijn lokaal staat alles al klaar en heb je een breder scala tot je beschikking. Hangt ook af van client wat er passend is: soms is het te onrustig met alle instrumenten die overal staan, teveel indrukken, overprikkeling. Soms werkt het prima. Leeftijd heeft hier ook mee te maken: pubers willen natuurlijk niet meer op kleine trommeltjes spelen, en willen serieuze instrumenten zoals drumstel of basgitaar etc.

- Doet uw dit individueel of in groepen of allebei?

  Individueel, duo's en groepen zijn mogelijk, maar over het algemeen individueel

- Wat voor oefeningen doet uw met de kinderen/cliënten (en verschilt dit per leeftijd en aandoening)?

Dat is te divers om nu kort toe te lichten: met elk kind werk ik anders, want je sluit altijd aan bij zijn belevingswereld, mogelijkheden en interesses. Dat kan dus bij de een het leren van een instrument zijn, bv dat de ingang gitaar-les is, en onderliggend aan doelen gewerkt kan worden. Bij anderen is het improviserend spel, waarbij je tot interactie probeert te komen. Zeker bij niet-talige kinderen, die niet of nauwelijks praten, werk ik veel met imitatie en improvisatie. Klanken maken, contact uitlokken, klanken nadoen, kijken of er op die manier interactie kan ontstaan, wederkerigheid, samenwerking etc. Dat gaat via allerlei fases die Karin Schumacher mooi beschreven heeft (zoek op contactmodi, anders kan ik je het document wel sturen als je het niet makkelijk kan vinden). Muziek = samenwerking over het algemeen: je moet naar elkaar luisteren, met elkaar rekening houden, op elkaar afstemmen, om het aanstekelijk te laten klinken. Het is dus altijd van belang om te kijken in welke vorm (of oefening) je iets kan gieten zodat het kind geinteresseerd en gemotiveerd is, een succeservaring op kan doen en vervolgens tot een leermoment kan komen.

- Welke instrumenten/voorwerpen gebruikt uw hierbei?

Klankstaven, keyboard, piano, percussie, drumstel, gitaat, basgitaar, ukelele, regenmaker, oceandrum, laptop, beats, microfoon, opname apparatuur, stem, etc. Alle soorten instrumenten die passend lijken.

- Wat voor vaardigheden oefent uw met de kinderen/cliënten?

Expressie: uiten van gevoel, emotie, belevingswereld, gedachten
Zelfbeeld: zelfvertrouwen, identiteit, wie ben je, wat is belangrijk voor je, waar heb je hulp bij nodig
Sociaal: interactieve vaardigheden – rekening houden, beurt wachten, samenwerken, luisteren etc

- Wat is het doel van de therapie?

Tot ontwikkeling komen op het gebied waar een hulpvraag is. Vaak komt die vanuit ouders of verzorgers, omdat een kind zich moeilijk kan uiten en daardoor teruggetrokken of juist agressief/externaliserend gedrag laat zien. Muziek kan een ingang zijn om tot uiten van gevoel te komen, en daarnaast ook te oefenen met bovengenoemde vaardigheden

- In hoeverre verschilt de reactie van de kinderen/cliënten?

Elk kind is anders, dus bij iedereen verschilt de reactie. Gemeenschappelijke deler is dat bijna elk kind van muziek houdt, nieuwsgierig en geinteresseerd is naar muziekinstrumenten, en dus ook gemakkelijk te motiveren is voor muziektherapie. Ook zie je dat kinderen die normaal gesproken erg teruggetrokken en in hun eigen wereldje kunnen zijn, via muziek opeens tot veel meer interactie kunnen komen dan via de gangbare weg: taal. Doordat er geen taalbarriere is, en je gewoon met elkaar kunt 'spelen' gaat het contact maken soms veel makkelijker en kunnen kinderen opeens wel 45 minuten lang SAMEN iets doen ipv in hun eentje.

Met vriendelijke groet,   Nadine Spigt muziektherapeut

2. Touch sensing

Capacitive touch sensing is a technique for measuring the touch (or close proximity) of a finger to an electrical conductor. It works by injecting a periodic electrical signal on a conductive material and measuring the signal after flowing through the material. When a finger is close enough it forms a weak conductive link with the conductive material. This slightly alters the signal, allowing for detection of a touch event.
This simple interaction can be multiplied to enrich its expressiveness. Many touchscreens are based on a capacitive touch matrix on a planar surface and it has also been implemented for multiple users (Deitz et al., 2001) [45]. Sato et al. (2012) developed a capacitive touch sensing technique for everyday objects that captures not only if but also how an object is touched. The technique is called Swept Frequency Capacitive Sensing (SFCS) and uses analysis of a wide range of frequencies of the signal in combination with machine learning. SFCS can for example be used to determine whether a doorknob is touched with one finger, two fingers, a whole hand or not at all [46].

Ono et al. (2013) developed a similar sensing technique for touch and hand posture sensing in everyday objects called Active Acoustic Sensing (AAS). It is based on a vibration speaker and a piezo-electric element. By injecting a sweeping vibration signal on in object and picking it up with the piezo, the resonance of the object in different frequencies can be measured. The resonance changes depending on how an object is touched. With this technique it is possible to measure e.g. on which side a plastic toy is being touched. The applied pressure of the touch can also be detected [47].

3. Mechanical prototype

Before the working prototype a mechanical version of the prototype was made. Some of the design solutions in this version were not functional or elegant enough and therefore a decision was made to redesign those parts. In the mechanical prototype the springs are mounted on a rectangular wooden board (see figure A.1|3). Because of this there is no place to hide the Arduino and electronic circuit, which is something that needed to be improved. The springs and the steel cylinders (A.1|2) are mounted to the board using bolts and nuts and custom-made washers with multiple holes (A.1|4).

For each spring, three nuts are used to hold them in place. This solution was not very elegant, because one of the three nuts could not be screwed all the way down due to wire of the spring being in its way. Furthermore, attaching the steel cylinders with bolts meant that they could not be hollow from the inside to run the cables from the sensors through them. This meant that new solutions for attaching the springs and cylinders had to be found. Moreover, the platforms on the springs (A.1|5) had to be redesigned. They all have a slight tilt relative to the wooden board as can be seen in figure 4.9. This is because the custom-made washers (A.1|1) used to screw them to the springs do not have a big enough notch for the wire of the spring to go through. Furthermore, the piezos can not lay flat on the surface of the platforms due to their solder points.

In the redesign the platforms are mounted to the springs in a different way so that they are approximately horizontal. They should also have a small notch for the solder points to fit in.

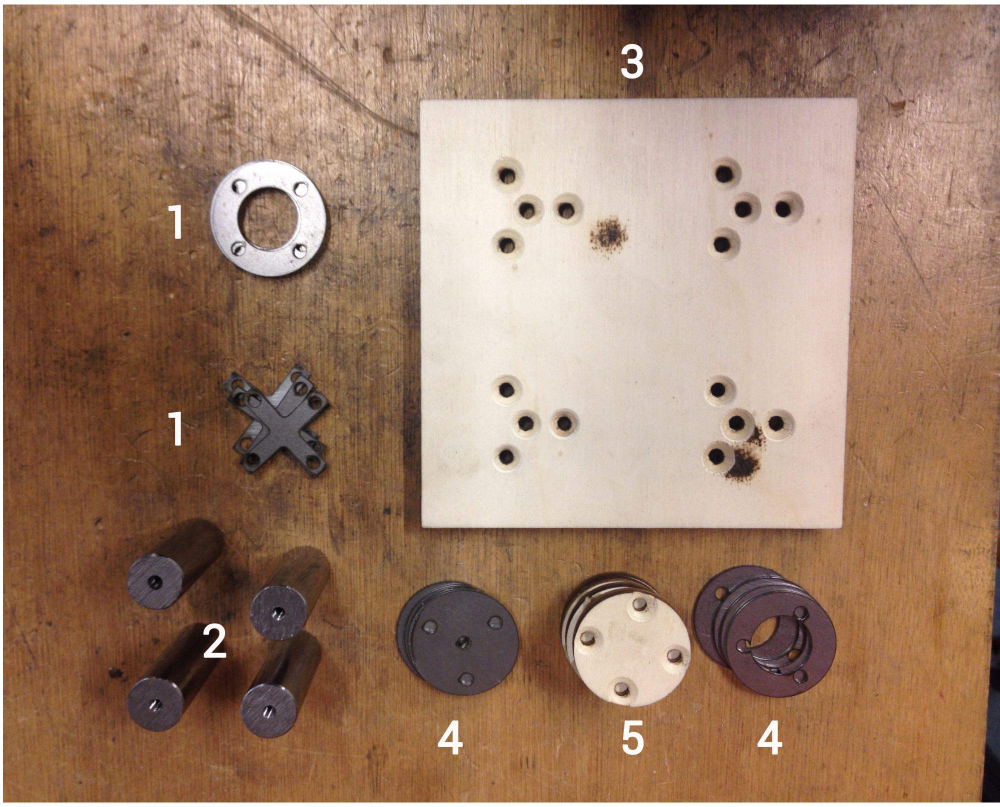

Figure A.1 *Mechanical prototype parts*

4. Arduino code

```
#include <MIDI.h>
MIDI_CREATE_DEFAULT_INSTANCE();

#include <Wire.h>
#include <Adafruit_MMA8451.h>
#include <Adafruit_Sensor.h>
Adafruit_MMA8451 mma = Adafruit_MMA8451();

byte noteOn = 144;

int piezo = 0;//storage for activated piezo
int threshold = 120;//anything over this means we've hit the piezo
int thresholdPressure = 10;//anything over this means we've pressed the
pressure sensor
int thresholdRotation = -8192;//anything over this means we've tilted
the sensor

//Mux control pins
int s0 = 8;
int s1 = 9;
int s2 = 10;
int s3 = 11;

//Mux in "SIG" pin
int SIG_pin = A0;

int flex1 = A2;
int flex2 = A3;
int flex4 = A1;

int button1 = 2;
int button2 = 3;
int button3 = 4;
int button4 = 5;
int button5 = 6;
int ledPin = 7;
int ledState = 1;
boolean currentState1 = LOW;//stroage for current button state
boolean lastState1 = LOW;//storage for last button state
boolean currentState2 = LOW;
boolean lastState2 = LOW;
boolean currentState3 = LOW;
boolean lastState3 = LOW;
boolean currentState4 = LOW;
```

```
boolean lastState4 = LOW;
boolean currentState5 = LOW;
boolean lastState5 = LOW;

void setup(){

      //Accelerometer test
      Serial.begin(9600);

      Serial.println("Adafruit MMA8451 test!");

      if (! mma.begin()) {
            Serial.println("Couldnt start");
            while (1);
      }
      Serial.println("MMA8451 found!");

      mma.setRange(MMA8451_RANGE_2_G);

      Serial.print("Range = "); Serial.print(2 << mma.getRange());
      Serial.println("G");


      //button & LED pin setup
      pinMode(2, INPUT);
      pinMode(3, INPUT);
      pinMode(4, INPUT);
      pinMode(5, INPUT);
      pinMode(6, INPUT);
      pinMode(ledPin, OUTPUT);


      //MUX pin setup
      pinMode(s0, OUTPUT);
      pinMode(s1, OUTPUT);
      pinMode(s2, OUTPUT);
      pinMode(s3, OUTPUT);

      digitalWrite(s0, LOW);
      digitalWrite(s1, LOW);
      digitalWrite(s2, LOW);
      digitalWrite(s3, LOW);

      Serial.begin(9600);

}
```

```
void loop(){

      int piezo1Val = readMux(0);
      int piezo2Val = readMux(1);
      int piezo3Val = readMux(2);
      int piezo4Val = readMux(3);

      int flex1Val = analogRead(flex1);
      int flex2Val = analogRead(flex2);
      int flex3Val = readMux(4);
      int flex4Val = analogRead(flex4);

// piezos(and pressure
sensors):---------------------------------------------------
      if (piezo1Val>threshold){
            int freq1 = map(flex1Val, 0, 1023, 6, 1);
            byte pitch1 = byte(freq1) * 12 + 6;
            int piezo = activatedPiezo(0);
            byte velocity = getVelocity(piezo1Val);
            byte delayTime1 = getDelayTime(piezo1Val);

            MIDI.sendNoteOn(pitch1,velocity,1);
            delay(delayTime1);
            MIDI.sendNoteOff(pitch1,0,1);
      }

      if (piezo2Val>threshold){
            int freq2 = map(flex2Val, 0, 1023, 6, 1);
            byte pitch2 = byte(freq2) * 12 + 2;
            int piezo = activatedPiezo(1);
            byte velocity2 = getVelocity(piezo2Val);
            byte delayTime2 = getDelayTime(piezo2Val);

            MIDI.sendNoteOn(pitch2,velocity2,1);
            delay(delayTime2);
            MIDI.sendNoteOff(pitch2,0,1);
      }

      if (piezo3Val>threshold){
            int freq3 = map(flex3Val, 0, 1023, 6, 1);
            byte pitch3 = byte(freq3) * 12 + 8;
            int piezo = activatedPiezo(2);
            byte velocity3 = getVelocity(piezo3Val);
            byte delayTime3 = getDelayTime(piezo3Val);

            MIDI.sendNoteOn(pitch3,velocity3,1);
            delay(delayTime3);
```

```
            MIDI.sendNoteOff(pitch3,0,1);
      }

            if (piezo4Val>threshold){
            int freq4 = map(flex4Val, 0, 1023, 6, 1);
            byte pitch4 = byte(freq4) * 12 + 4;
            int piezo = activatedPiezo(3);
            byte velocity4 = getVelocity(piezo4Val);
            byte delayTime4 = getDelayTime(piezo4Val);

            MIDI.sendNoteOn(pitch4,velocity4,1);
            delay(delayTime4);
            MIDI.sendNoteOff(pitch4,0,1);
      }


//accelerometer: -------------------------------------------------------

  // Read the 'raw' data in 14-bit counts
  mma.read();

  if (mma.x>thresholdRotation){
      byte rotationX = map(mma.x, -8192, 8191, 127, 0);
      MIDI.sendNoteOn(rotationX,127,6);
      delay(50);
    }

  if (mma.y>thresholdRotation){
      byte rotationY = map(mma.y, -8192, 8191, 127, 0);
      MIDI.sendNoteOn(rotationY,127,7);
      delay(50);
    }

  if (mma.z>thresholdRotation){
      byte rotationZ = map(mma.z, -8192, 8191, 0, 127);
      MIDI.sendNoteOn(rotationZ,127,8);
      delay(50);
    }


//buttons:---------------------------------------------------------
  currentState1 = digitalRead(button1);
  if (currentState1 == HIGH && lastState1 == LOW){//if button has just
been pressed
    MIDI.sendNoteOn(127,127,9);
    delay(1);//crude form of button debouncing
  } else if(currentState1 == LOW && lastState1 == HIGH){
```

```
  MIDI.sendNoteOff(127,0,9);
  delay(1);//crude form of button debouncing
}
lastState1 = currentState1;

currentState2 = digitalRead(button2);
if (currentState2 == HIGH && lastState2 == LOW){
  MIDI.sendNoteOn(127,127,10);
  delay(1);
} else if(currentState2 == LOW && lastState2 == HIGH){
  MIDI.sendNoteOff(127,0,10);
  delay(1);
}
lastState2 = currentState2;

currentState3 = digitalRead(button3);
if (currentState3 == HIGH && lastState3 == LOW){
  MIDI.sendNoteOn(127,127,11);
  delay(1);
} else if(currentState3 == LOW && lastState3 == HIGH){
  MIDI.sendNoteOff(127,0,11);
  delay(1);
}
lastState3 = currentState3;

currentState4 = digitalRead(button4);
if (currentState4 == HIGH && lastState4 == LOW){
  MIDI.sendNoteOn(127,127,12);

  //toggle LED on/off
  if (ledState == 0) {
    digitalWrite(ledPin, HIGH);// Toggle on
    ledState = 1;
  } else {
    digitalWrite(ledPin, LOW);// Toggle off
    ledState = 0;
  }

  delay(1);
} else if(currentState4 == LOW && lastState4 == HIGH){
  MIDI.sendNoteOff(127,0,12);
  delay(1);
}
lastState4 = currentState4;

currentState5 = digitalRead(button5);
if (currentState5 == HIGH && lastState5 == LOW){
```

```
    MIDI.sendNoteOn(127,127,13);
    delay(1);
  } else if(currentState5 == LOW && lastState5 == HIGH){
    MIDI.sendNoteOff(127,0,13);
    delay(1);
  }
  lastState5 = currentState5;

}


//MUX functions:--------------------------------------------------------
int readMux(int channel){
  int controlPin[] = {s0, s1, s2, s3};

  int muxChannel[5][4]={
    {0,0,0,0}, //channel 0
    {1,0,0,0}, //channel 1
    {0,1,0,0}, //channel 2
    {1,1,0,0}, //channel 3
    {0,0,1,0}, //channel 4
  };

  //loop through the 5 sig
  for(int i = 0; i < 5; i ++){
    digitalWrite(controlPin[i], muxChannel[channel][i]);
  }

  //read the value at the SIG pin
  int val = analogRead(SIG_pin);

  //return the value
  return val;
}


//piezo functions: ----------------------------------------------------
int activatedPiezo (int activatedPiezo){
  int thisPiezo = activatedPiezo;
  return thisPiezo;
}

int getVelocity (int piezoVal){
  int maxPiezoVal = getMaxVal(piezoVal);
  byte velocity = map(maxPiezoVal, 400, 1000, 40, 127);//velocity
between 50 and 127 based on max val from piezo
  return velocity;
```

```
}

int getDelayTime (int piezoVal){
  int maxPiezoVal = getMaxVal(piezoVal);
  byte delayTime = maxPiezoVal;
  return delayTime;
}

int getMaxVal(int lastVal){
  int currentVal = readMux(piezo);
  while (currentVal>lastVal){
    lastVal = currentVal;
    currentVal = readMux(piezo);
  }
  return lastVal;
}
```

5. List of springs

The compression springs that were tested can be seen in table A.1. They were ordered from the Tevema webshop*. Spring number 2 was used used in the final prototype.

Sping nr.	Article nr.	Wire diameter (mm)	Length Lo (mm)	Outer diameter (mm)	Amount
1	D11598C	0,7	136	12	4
2	D12097B	1	100	18,5	4
3	D12346	1,25	116	19	4

Table A.1 *Compression springs*

* www.tevema.com/webshop_nl.html

6. Prototype cost calculation

The mechanical parts and materials for the prototype were available in the workshop at the University of Twente with the exception of the compression springs. Because of this the production price of the prototype would mainly depend on the the number of pods and the price of the electronics. Table A.2 shows three different configurations of parts and how many parts are needed for 3, 4, 6 ,7 or 9 pods. The parts that are used in all of the three configurations are shown in the green part. The specific parts for each configuration have

Number of Pods		3		4		6		7		9	
Standard parts	Price in Euro	Number	Price	Number	Price	Number	Price	Number	Price	Number	Price
Piezo	0,54	3	1,62	4	2,16	6	3,24	7	3,78	9	4,86
Rotary knob	2,8	1	2,8	1	2,8	1	2,8	1	2,8	1	2,8
Button	0,06	5	0,3	5	0,3	5	0,3	5	0,3	5	0,3
LED	0,04	8	0,32	8	0,32	8	0,32	8	0,32	8	0,32
Button with integrated LED	2,66	2	5,32	2	5,32	2	5,32	2	5,32	2	5,32
ProtoShield	2	1	2	1	2	1	2	1	2	1	2
16-channel MUX breakout	5,5	0	0	1	5,5	1	5,5	1	5,5	1	5,5
Resistors	0,05 (for 5x)	10	0,1	10	0,1	20	0,2	20	0,2	20	0,2
Triple axis accelerometer	9,5	0	0	1	9,5	1	9,5	2	19	2	19
	Subtotal		12,46		28		29,18		39,22		40,3
A	+										
Flex sensor	14	3	42	4	56	6	84	7	98	9	126
	Total a		54,46		84		113,18		137,22		166,3
or **B**											
Conductive thread	3,25	1	3,25	1	3,25	1	3,25	1	3,25	1	3,25
Knit jersey conductive fabric	11	1	11	1	11	1	11	1	11	1	11
Fusable interfacing	4,95	1	4,95	1	4,95	1	4,95	1	4,95	1	4,95
	Total b		31,66		47,2		48,38		68,42		59,5
or **C**											
Conductive thread	3,25	1	3,25	1	3,25	1	3,25	1	3,25	1	3,25
Knit jersey conductive fabric	11	1	11	1	11	1	11	1	11	1	11
Duct tape	10	1	10	1	10	1	10	1	10	1	10
	Total c		36,71		52,25		53,43		63,47		64,55

Table A.2 *Prototype cost calculation*

a differently coloured background (blue, red, grey). The first option is to use a flex sensor to measure how hard the pod is being pushed by the user (A.2|A). The second option is to use a hand-made pressure sensor for this (A.2|B). The last option is version of the pressure sensor that uses different materials (A.2|C). Of the three the second configuration was chosen because it is the chapest option and it also works better than option three. It has a better texture than configuration C because instead of duct tape is used as a material to make the pressure sensor. Configuration B was only so cheap because the neoprene was already available for free. Option C was chosen over option A because it is musch easier to integrate into the redesigned pods with the compression springs.

7. Usability test questionnaire

Dutch version

Tangible pods usability test No.

Datum:

Leeftijd:

Geslacht:

Heeft u een verstandelijke beperking? Zo ja, wat voor een?

Heeft u ervaring met muziek maken?

☐ Nee ☐ Een beetje

☐ Veel ☐ Ik doe het professioneel

Vul deze vragen na de eerste test van de interface in:

		Helemaal <u>niet</u> mee eens 1	2	3	4	Helemaal mee eens 5
1	Ik zou deze interface vaak willen gebruiken					
2	Ik vond de interface onnodig ingewikkeld					
3	Ik vond de interface makkelijk te gebruiken					
4	Ik zou ondersteuning van een technisch persoon nodig hebben om deze interface te kunnen gebruiken					
5	De verschillende functies waren goed geïntegreerd in deze interface (denk aan het maken van verschillende geluiden)					
6	Ik vond dat de onderdelen van de interface geen logische samenhang hadden					
7	Ik denk dat de meeste mensen snel zouden kunnen leren hoe ze deze interface kunnen gebruiken					
8	Ik vond deze interface heel moeilijk te gebruiken					
9	Ik voelde me heel zelfverzekerd tijdens het gebruiken van deze interface					
10	Ik zou nog veel moeten leren voordat ik deze interface echt zou kunnen gebruiken					

Vul deze vragen na de tweede test van de interface in:

		Helemaal niet mee eens 1	2	3	4	Helemaal mee eens 5
1	Ik zou deze interface vaak willen gebruiken					
2	Ik vond de interface onnodig ingewikkeld					
3	Ik vond de interface makkelijk te gebruiken					
4	Ik zou ondersteuning van een technisch persoon nodig hebben om deze interface te kunnen gebruiken					
5	De verschillende functies waren goed geïntegreerd in deze interface (denk aan geluiden maken en 'loopen')					
6	Ik vond dat de onderdelen van de interface geen logische samenhang hadden					
7	Ik denk dat de meeste mensen snel zouden kunnen leren hoe ze deze interface kunnen gebruiken					
8	Ik vond deze interface heel moeilijk te gebruiken					
9	Ik voelde me heel zelfverzekerd tijdens het gebruiken van deze interface					
10	Ik zou nog veel moeten leren voordat ik deze interface echt zou kunnen gebruiken					

Open vragen

1. Zijn er nog dingen die u graag zou willen veranderen aan de interface? Zo ja, welke?

2. Heeft u nog reacties of aanmerkingen?

Bedankt voor het meedoen!

English version

Tangible pods usability test No.

Date:

Age:

Gender:

Do you have a cognitive disablility? If so, which?

Do you have experience in making music?

❐ No ❐ A little

❐ A lot ❐ I'm a professional

Please fill in these questions after using the interface for the first time:

		Strongly disagree				Strongly agree
		1	2	3	4	5
1	II would like to use this interface more often					
2	I found the interface to be unnecessarily complicated					
3	Using the interface was easy					
4	I would need assistance from a technical person to use the interface properly					
5	I found the various functions in this interface were well integrated (think of making different sounds)					
6	I thought there was too much inconsistency in this interface					
7	I would imagine that most people would learn to use this interface very quickly					
8	I found the interface very cumbersome to use					
9	I felt very confident using the interface					
10	I needed to learn a lot of things before I could get going with this interface					

Please fill in these questions after using the interface for the second time:

		Strongly disagree 1	2	3	4	Strongly agree 5
1	II would like to use this interface more often					
2	I found the interface to be unnecessarily complicated					
3	Using the interface was easy					
4	I would need assistance from a technical person to use the interface properly					
5	I found the various functions in this interface were well integrated (think of making different sounds and looping the sounds)					
6	I thought there was too much inconsistency in this interface					
7	I would imagine that most people would learn to use this interface very quickly					
8	I found the interface very cumbersome to use					
9	I felt very confident using the interface					
10	I needed to learn a lot of things before I could get going with this interface					

Open questions

1. Are there things you would like to change about the interface? If so, which and how?

2. Do you have other reactions or suggestions?

Thank you for participating!

8. Usability test results

Participant Nr.	1	2	3	4	5	6	7
A Personal information							
Age	23	21	25	25	23	26	27
Gender	m	m	m	m	f	f	m
Cognitive disability	None	Asperger's syndrome	Attention Deficit Hy-peractivity Disorder (ADHD), Autism	None	None	None	None
Experience with making music	None	A lot	None	A lot	A little	None	A lot
B SUS 1	1 (strongly disagree), 2 (disagree a little), 3 (neutral), 4 (agree a little), 5 (strongly agree)						
1. I would like to use this interface more often	3	3	1	4	2	3	3
2. I found the interface to	2	1	1	3	1	2	1
3. Using the interface was easy	4	3	5	4	3	3	5
4. I would need assistance from a technical person to use the interface properly	1	1	1	4	1	5	1
5. I found the various functions in this interface were well integrated (think of making different sounds)	3	4	5	3	3	3	2
6. I thought there was too much inconsistency in this interface	2	1	1	4	3	2	2
7. I would imagine that most people would learn to use this interface very quickly	4	4	5	4	4	4	5

Table A.3 *Usability test results (part 1 of 3)*

8	9	10	11	12	13	Average	Average with cog. dis.	Average without cog. dis.
20	22	34	20	20	28	24,154	24,667	23,714
m	m	m	m	m	m	11/2 (m/f)	all male	5/2 (m/f)
None	None	Asperger's syndrome	PDD-NOS	ASD	Autism	6/7 (with/ without cognitive dis- ability)		
None	A lot	A little	A lot	A little	None	5 none, 3 a little, 5 a lot	2 none, 2 a little, 2 a lot	3 none, 1 a little, 3 a lot
2	3	3	4	2	2	2,692	2,5	2,875
1	1	1	2	2	2	1,538	1,5	1,571
5	4	3	4	3	4	3,846	3, 667	4
1	1	2	1	2	1	1,692	1,333	2
4	4	3	4	4	2	3,385	3,167	3,143
2	5	4	1	3	4	2,615	2,333	2,857
4	5	3	3	4	5	4,154	4	4,286

Participant Nr.	1	2	3	4	5	6	7
8. I found the interface very cumbersome to use	2	1	1	2	3	4	1
9. I felt very confident using the interface	3	3	?	3	2	1	3
10. I needed to learn a lot of things before I could get going with this interface	4	1	5	2	3	5	2
SUS score 1	65	80	77	57,5	57,5	40	77,5

C SUS 2	1 (strongly disagree), 2 (disagree a little), 3 (neutral), 4 (agree a little), 5 (strongly agree)						
1. I would like to use this interface more often	4	3	3	3	3	2	5
2. I found the interface to be unnecessarily complicated	2	2	3	3	2	4	2
3. Using the interface was easy	4	3	5	4	3	2	5
4. I would need assistance from a technical person to use the interface properly	2	1	1	4	1	5	4
5. I found the various functions in this interface were well integrated (think of making different sounds, looping the sounds)	3	3	5	3	2	3	2
6. I thought there was too much inconsistency in this interface	2	4	1	4	4	3	1
7. I would imagine that most people would learn to use this interface very quickly	4	5	5	4	3	4	5
8. I found the interface very cumbersome to use	1	1	1	3	4	3	2

Table A.3 *Usability test results (part 2 of 3)*

8	9	10	11	12	13	Average	Average with cog. dis.	Average with-out cog. dis.
1	1	1	2	2	1	1,692	1,333	2
5	4	3	3	3	2	2,917 (?)	2,8 (?)	3
3	1	4	3	2	3	2,923	3	2,857
80	77,5	57,5	72,5	65	60	66,692	68,667	65
2	1	4	4	2	3	3	3,167	2,857
1	1	2	1	1	1	1,923	1,667	2,143
5	4	4	4	3	4	3,846	3,833	3,857
1	?	1	2	4	1	2,25 (?)	1,667	2,833
4	4	3	4	5	4	3,462	3,667	3
2	1	2	2	3	2	2,385	2,333	2,429
4	5	4	3	4	5	4,231	4,333	4,143
1	1	1	1	2	1	1,692	1,167	2,143

Participant Nr.	1	2	3	4	5	6	7
9. I felt very confident using the interface	4	3	?	3	3	1	5
10. I needed to learn a lot of things before I could get going with this interface	2	1	1	2	3	4	2
SUS score 2	75	70	88	52,5	60	32,5	77,5

D SUS score 1 - SUS score 2	-10	10	-11	5	-2,5	7,5	0

Participant Nr.	1	2	3	4	5	6
A Open questions						
1. Are there things you would like to change about the interface? If so, which and how?	Touchpads could be more sensitive, there is a short delay that you need to get used to if you want to make a drum part, the undo and erase button seem to do the same.	It should be more constant, then it would be very useful.		Something that shows the length of the loop and it's timing; shifting the timing of sounds in the loop.	It is difficult to use the interface because you do not get direct feeback. You would expect something like a play-stop button.	I would like to see more colors in the interface!

8	9	10	11	12	13	Average	Average with cog. dis.	Average without cog. dis.
5	4	4	3	3	4	3,5 (?)	3,4 (?)	3,571
3	1	3	3	2	2	2,231	2	2,429
80	79,75	75	72,5	62,5	82,5	69,827	75,083	65,321
0	-2,25	-17,5	0	2,5	-22,5			

Table A.3 *Usability test results (part 3 of 3)*

7	8	9	10	11	12	13
Being able to set the length of the loop, maybe adding sounds myself, but that depends on the interface. More buttons [pods] would be nice.	Maybe being able to change the length of the loops, for advanced people that is.	The translation from pressing to sound could be a lot more precise.	The response on the pods should be a little more sensitive and the layers from recording a loop should be more in the background so they do not distract from the sounds that are actively made.	More sounds.	Buttons [pods] did not feel equally reliable.	Some sounds are not easy to reproduce.

Table A.4 *Open questions and themes (part 1 of 2)*

Participant Nr.	1	2	3	4	5	6
2. Do you have other reactions or suggestions?	If you click on undo the loop could keep playing, the loop function is a very valuable addition.			[The interface] shifts on the surface of the table; which action results in which reaction?; being able to manipulate each loop [layer], first making sounds and then manipulating them -> stretch, filters, echo, etc.	I thought it was difficult to differentiate the sounds, because of the lag between them and because the sounds echo.	Because I do not have any previous experience making music, I was difficult for me using the interface. Although it was funny.
B Notable expressions		"It is weird at first and then you get what you could do with it" [about the looping-function]; "The springs make it very interesting but sometimes it is difficult to do something in rhythm and it is out of rhythm"	"What is this for?"; "But autistic people are not stupid, is it for stupid people?"; "You want to make other kinds of sounds"; "The undo button immediatly takes everything away"		"Other sounds would be nicer"	"I see it more as a toy to play with"

Table A.4 *Open questions (part 2 of 2)*

7	8	9	10	11	12	13
It is nice.			Seeing that it is in prototype phase, small mechanical improvements could be made (feels a liitle shaky). Except for that no reactions worth stating.			
	“Very funny and weird”	“I cannot figure out when it makes the same tone and when a different tone, while I am pressing the same thing [pod]”	“It is similar to a drum where some parts are more sensible than others”, “I notice it makes sounds only when you release [after pressing]”, “It makes different sounds depending on how hard you press on it.”	“It is a strange thing”	“It is not consistant”, “It is an odd thing”	“It was not exactly intuitive for me”, “It is different, but nice”, “The sounds are very similar to each other instead of each thing [pod] having ist own distinct sound”

Participant Nr.	1	2	3	4	5	6
Themes open questions and **expressions**						
Pods	Touchpads could be more sensitive					
Erase'- and 'undo'-button	The undo and erase button seem to do the same, If you click on undo the loop could keep playing		"The undo button im-mediatly takes everything away"			
Delay	There is a short delay that you need to get used to if you want to make a drum part				It is difficult to use the inter-face because you do not get direct feeback	

Table A.5 *Themes (part 1 of 3)*

7	8	9	10	11	12	13
More buttons [pods] would be nice.			The response on the pods should be a little more sensitive. "It is similar to a drum where some parts are more sensible than others", "I notice it makes sounds only when you release [after pressing]", "It makes different sounds depending on how hard you press on it."		Buttons [pods] did not feel equally reliable.	

Participant Nr.	1	2	3	4	5	6
Audio feed-back		It should be more con-sistant, then it would be very useful		which ac-tion results in which reac-tion?		
Loop-func-tion		"It is weird at first en then you get what you could do with it [...] sometimes it is difficult to do something in rhythm and it is out of rhythm" [about the looping-func-tion]		Something [needs to be added] that shows the length of the loop and it's timing; being able to ma-nipulate each loop [layer], first making sounds and then manipu-lating them -> stretch, filters, echo, etc., shifting the timing of sounds in the loop	You would expect some-thing like a play-stop button.	
Ergonomics				[The inter-face] shifts on the surface of the table		

7	8	9	10	11	12	13
		The translation from pressing to sound could be a lot more precise. "I cannot figure out when it makes the same tone and when a different tone, while I am pressing the same thing [pod]"			"It is not consistant"	Some sounds are not easy to reproduce.
Being able to set the length of the loop	Maybe being able to change the length of the loops, for advanced people that is.		the layers from recording a loop should be more in the background so they do not distract from the sounds that are actively made.			

Table A.5 *Themes (part 2 of 3)*

Participant Nr.	1	2	3	4	5	6
Sounds			“You want to make other kinds of sounds”		I thought it was difficult to differentiate the sounds, because of the lag between them and because the sounds echo. “Other sounds would be nicer”	
Visual appearance						I would like to see more colors in the interface!
Usability						Because I do not have any previous experience making music, I was difficult for me using the interface.
General reactions		“The springs make it very interesting”	What is this for?; “But autistic people are not stupid, is it for stupid people?”			Although it was funny. “I see it more as a toy to play with”

Table A.5 *Themes (part 3 of 3)*

7	8	9	10	11	12	13
maybe adding sounds myself, but that depends on the interface				More sounds.		“The sounds are very similar to each other instead of each thing [pod] having ist own distinct sound”
						“It was not exactly intuitive for me”
It is nice.	“Very funny and weird”		Seeing that it is in prototype phase, small mechanical improvements could be made (feels a liitle shaky)	“It is a strange thing”	“It is an odd thing”	“It is different, but nice”

9. Kinetic sand interface and usability test videos (DVD)