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Participatory Design (PD) of a Collaborative Accessible Digital Musical Interface (CADMI) for Children with Autism Spectrum Condition (ASC) to Enhance Co-located Collaboration Skills

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Abstract:

This thesis project aims to address the challenges faced by children with autism spectrum condition (ASC) by developing a collaborative and accessible digital musical interface (CADMI) through a participatory design (PD) process. The primary goal of the study is to foster collaboration, cooperative play, and communication skill development among children with ASC by creating a technological prototype for musical co-creation. To ensure the project's relevance and effectiveness, six PD workshops were conducted in collaboration with Stanbridge Academy (n=6) and Skolen Sputnik (n=6). These workshops incorporated fictional inquiry narratives and tailored non-digital activities, taking into account the unique strengths of individuals with ASC. The resulting prototype, called 'boxsound', prioritises the user's perspective and enables the practice of various social skills by bridging divergent viewpoints. A case study involving three ASC children was conducted to evaluate the prototype's engagement, functionality, aesthetics, and subjective quality using the Mobile Application Rating Scale: user version (uMARS). Additionally, a semi-structured interview was conducted with two SEN teachers to assess the prototype's effectiveness in special needs education. By integrating theoretical foundations, participatory design approaches, and interdisciplinary perspectives, this research contributes to the expanding knowledge base in PD and CADMIs. Its ultimate aim is to enhance the lives of children with ASC and inspire future research endeavours in this field.

Contents

List of Figures

List of Tables

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This thesis project aims to address the challenges faced by children with autism spectrum condition (ASC) by developing a collaborative and accessible digital musical interface (CADMI) through a participatory design (PD) process. The primary goal of the study is to foster collaboration, cooperative play, and communication skill development among children with ASC by creating a technological prototype for musical co-creation. To ensure the project's relevance and effectiveness, six PD workshops were conducted in collaboration with Stanbridge Academy (n=6) and Skolen Sputnik (n=6). These workshops incorporated fictional inquiry narratives and tailored non-digital activities, taking into account the unique strengths of individuals with ASC. The resulting prototype, called 'boxsound', prioritises the user's perspective and enables the practice of various social skills by bridging divergent viewpoints. A case study involving three ASC children was conducted to evaluate the prototype's engagement, functionality, aesthetics, and subjective quality using the Mobile Application Rating Scale: user version (uMARS). Additionally, a semi-structured interview was conducted with two SEN teachers to assess the prototype's effectiveness in special needs education. By integrating theoretical foundations, participatory design approaches, and interdisciplinary perspectives, this research contributes to the expanding knowledge base in PD and CADMIs. Its ultimate aim is to enhance the lives of children with ASC and inspire future research endeavours in this field.

CCS Concepts: • **Human-centered computing** → *Accessibility systems and tools.*

Additional Key Words and Phrases: Accessibility, Individuals with Disabilities, Human-AI Interaction, Participatory Design

1 INTRODUCTION

Worldwide it is estimated that one out of 100 children has autism spectrum condition (ASC) [60]. Autism is a diverse neurodevelopmental condition that can profoundly affect the physical and mental well-being of those living with it—common challenges faced are social interactions due to lack of emotional regulations [46], communication difficulties [40], repetitive patterns of behaviour [81]. Therefore, individuals with autism often encounter obstacles in everyday activities, such as engaging in social interactions and participating in collaborative leisure pursuits. Extensive research has indicated that evidence-based psychological interventions [63] can offer a quality of life improvement for individuals with autism, including the improvement of social skills [13, 47, 67], reduction of anxiety [14], and enhancement of maternal well-being [50].

This thesis explores and reflects upon the implementation of a participatory design (PD) process [69] involving two special needs education schools. We explore how PD can be applied to create a collaborative accessible digital musical interface (CADMI) [37] for children with ASC to facilitate collaboration and cooperative play among them. Our focus area is awareness of others, collaboration ability and verbal and non-verbal communication. Evidence-based psychological intervention and treatment have shown significantly improved outcomes [58, 67] for children with ASC through methodological practice and development strategies to improve communication skills. Research suggests that facilitating collaboration through technology for children with ASC is a well-established method [85]. We connect the significance of established music therapy [29–31, 42] and movement therapy [57, 68, 74] interventions to the role of collaborative social development and aim further to investigate this through a collaborative, exploratory PD process.

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Engaging in technology co-creation with children with ASC poses distinctive and substantial challenges. However, within these groups, the potential for significant benefits from active involvement in the design process and meaningful contributions are often the greatest [23]. When working with children with neurodiversity, various factors, such as unequal power dynamics, limited means of expressing ideas, and the involvement of multiple stakeholders, including parents, teachers, and caregivers, contribute to a complex context that necessitates a balanced and empathetic approach to design work. Drawing upon the existing literature, we utilise a participatory action research [78] approach with a fictional inquiry [19] narrative to facilitate active participation. Throughout the project, we learned the importance of minimising distractions by utilising non-digital activities inspired by Handlungspielraum [51] and the IDEAS framework [6]. These activities are continuously adapted to accommodate and capitalise on the unique strengths of individuals with ASC. These activities are iteratively tailored to accommodate and leverage the unique strengths of ASC individuals based on suggestions by Ward et al. [78].

The design process culminates in the creation of a technological prototype grounded in theory and incorporating the diverse interdisciplinary perspectives of students, teachers, and academic professionals [65]. These perspectives encompass various areas, including psychological theory and practice related to existing interventions for ASC and collaborative and play methodologies from the standpoint of interaction design and education. Nonetheless, the main prioritisation is the user's perspective throughout the process and how to bridge these perspectives and arrive at practical solutions. This is guided through an action research approach [22] where the goal of the project is to understand the user, design a product that they take part in shaping the development of, and finally evaluate the product within the target group. We uncover insights and suggestions for future research within the area of technological, therapeutic practices based on music and movement to help children with ASC develop their non-verbal communication skills and understanding.

The structure of the thesis is as follows: it commences with a comprehensive overview of current practices and interventions aimed at addressing ASC symptoms, providing essential background information for the research. This is followed by an extensive examination of collaboration and play methodologies utilising technology for children with ASC. Various research projects on accessible digital musical interfaces (ADMI) are introduced to present the current state-of-the-art in designing digital musical experiences for children with special needs. Next, we present our PD methods and outline the experimental design, technical tools, and project collaborators. This is followed by a preliminary series of user research workshops (URW) conducted at Stanbridge Academy, which set the stage for three participatory design workshops (PDW) conducted at Skolen Sputnik. The planning and preparation of both the URW and PDW activities are detailed, including the technical documentation highlighting the iterative design and development of the prototype based on the insights and discoveries made during these workshops. Finally, we reflect on the outcomes of a prototype case study, offering insights into the process and the methodological framework of collaborative musical experiences within the context of special education needs (SEN) schools. The objective is to extract generalisable insights from our experiences and contribute to the expanding knowledge base in the fields of PD and accessible digital musical interfaces (CADMI). The report concludes with a summary of key findings and a glimpse into future research endeavours.

The main contributions of this research are: (1) Through a participatory action research approach, it presents the process of co-creating an interdisciplinary technological CADMI prototype. (2) Interaction design paradigms for creating a shareable interface rooted in collaborative play methods and movement synchrony for children with ASC. (3) Perspectives and insights from SEN teachers and children with ASC on the effectiveness of a CADMI in an SEN setting.

2 RELATED WORK

In this section, we provide a concise overview of common challenges associated with autism spectrum conditions (ASC) and discuss widely adopted interventions that address these challenges. We then delve into the realm of music and movement therapy, exploring its effectiveness in supporting children with ASC in greater detail. Subsequently, we shift our focus to the analysis of digital collaboration and interactive play methodologies specifically designed for children with ASC. We examine how technology can facilitate collaboration among children in this context, culminating in an exploration of accessible sonic interaction in collaborative social activities. We highlight how technology enhances collaboration and present a range of cutting-edge examples of accessible digital musical interfaces designed for neurodiverse children.

2.1 Autism Spectrum Condition (ASC)

The term autism was first used to describe a neurophysiological disorder in 1943 by American psychiatrist Leo Kanner in his landmark paper *Autistic Disturbances of Affective Contact* [41]. Kanner used the term to describe a group of children who exhibited distinct symptoms, including social withdrawal, language delays, and repetitive behaviours. He referred to this condition as "early infantile autism". Since then, we have learned that symptoms of autism can vary substantially. Therefore, it has been commonly referred to as Autism Spectrum Disorder or, more recently, Autism Spectrum Condition (ASC), as there can be a spectrum of varieties of how the disorder presents itself in the individual case. Common occurrences of symptoms could be a person's ability to communicate and interact socially and repetitive behavioural patterns. It is a complex disorder that varies widely in its presentation and severity. ASC is typically diagnosed in early childhood, and its symptoms can persist throughout a person's lifetime. There is no known cure for ASC, but early intervention and treatment have shown significantly improved outcomes for individuals with the disorder [58, 67]. Treatment options may include various forms of therapy, medication, and special educational need (SNE) interventions tailored to the individual's needs. Less severe cases of autism are sometimes referred to as Asperger's syndrome, where speech and language skills are not as affected but often demonstrate restricted pragmatic language. Over the past few decades, the prevalence of ASC has increased, and research has advanced our understanding of the disorder. While there is still much to learn about ASC, continued research and advancements in diagnostic tools and treatments, have shown great potential to alleviate symptoms for individuals with ASC and their families.

2.1.1 Therapeutic Practices. The experience of ASC is highly diverse due to neurological differences, which results in a spectrum condition with varying communication needs, preferences, and strengths. This diversity highlights the significance of embodied experiences in shaping knowledge, including linguistic, creative, and behavioural expressions. These experiences are integral to developing effective interventions for children with ASC and essential for promoting their social, emotional, and cognitive well-being. Thus, there is no one-size-fits-all approach to treating ASC, and different individuals may benefit from other therapeutic practices. Treatment plans are, therefore, often tailored to the individual's needs and goals. Overall, the therapeutic practice aims to help individuals with ASC develop the skills to function independently and communicate more effectively [47, 67]. This section will list some of the most common forms of therapy for ASC, leading up to audio and bodily-based therapies, which will be presented more in-depth in the following sections.

- Applied Behaviour Analysis: Uses behavioural techniques to teach new skills and behaviours and to reinforce positive behaviours. ABA is often used with children with ASC to teach language, communication, and social skills [17]
- Relationship Development Intervention: Help establish and maintain reciprocal social relationships based on shared emotional experiences, empathy, and mutual trust [32]
- Theraplay: For young children with ASC who have difficulty with imaginative play, and help children and their caregivers build positive, nurturing relationships that promote healthy emotional and social

development through interactive, developmentally appropriate games and activities designed to promote positive interactions and bonding [1]

Other common forms of therapy not explicitly developed for ASC but often used as treatment could be *occupational therapy* which focuses on developing skills needed for daily living, such as dressing, grooming, and self-care. To help mitigate the fact that people with ASC often have a severe deficit in their communication skills, many excellent resources can be found within *speech and language therapy*, including language development, conversation skills, and nonverbal communication. For more severe cases of ASC, there is a broader psychological branch called *cognitive-behavioural therapy*, which is utilised to learn coping skills and manage anxiety and other emotional issues. Early adolescent ASC interventions have been found adequate by Narzis et al. [58]. Lastly, *social skills groups* are commonly used to support individuals with ASC. These therapies provide opportunities to practice social skills in a structured and supportive environment. They may include role-playing, group activities, and other exercises designed to help individuals with ASC learn how to interact with others more effectively.

2.1.2 Music Therapy for Children with ASC. For our research, we will take a closer look at music therapy as a form of symptom treatment for ASC. Music therapy has been widely used for ASC and has shown promising results in enhancing social, communication, and cognitive skills in individuals with autism [29–31, 42]. Music therapy can generally be described as a therapeutic session where music is used as a tool to facilitate non-musical goals. This could be, for example, improving communication, regulating emotions, and enhancing social interaction. Musical improvisation in music therapy is seen as a non-verbal language that allows both verbal and non-verbal individuals to connect emotionally and communicate without words [2]. While listening to music in a therapeutic setting involves an interactive process of choosing personally meaningful songs, exploring personal connections, and possibly reflecting on personal issues and associations related to the music [54]. Different forms of music therapy have been shown to be able to provide a unique and effective way to connect with individuals with autism and support their development.

In the systematic review by Mayer-Benarous et al. [53], we get a glimpse of the current state of music therapy and its effectiveness in interventions for children and adolescents with neurodevelopmental disorders (NDDs), including ASC. Examining 39 published empirical studies between 1970 and 2020 with 1774 participants, they argue that there are two main types of music therapy: educational and improvisational. Educational music therapy, also called interactive music therapy, has been found to affect individuals with ASC, particularly regarding speech production, positively [8]. At the same time, improvisational music therapy shows promising signs of affected social functioning for individuals with ASC [45].

Going back even further, there is a long history of using music therapy for treatment intervention for children with ASC. Resche et al. [64] examine the strengths and limitations of music therapy practice with children with autism from 1940-2009 and suggest directions for future music therapy research and clinical practice with this population. Despite limited research evidence, it argues that music therapy does show benefits for ASC intervention [64]. However, based on the literature they reviewed, it was found that there is an apparent lack of detail in intervention reporting and the need for larger sample sizes and well-designed comparative studies [64]. This similarly echoes Baker et al. [3] findings of a disconnection between published literature and practice within music therapy. Both argue the need for clinical validation of the many passed-down music therapy practices and techniques which do show great potential [3, 64].

Early examples of going beyond the classical forms of non-technological music therapy treatment include Adam Boulanger's [9] work on autism, new music technologies and cognition from 2010. Here, the author reports on developing and evaluating an application that measures cognitive abilities in central coherence tasks as part of a music composition task for children with Asperger's syndrome—suggesting that it is possible to embed cognitive measures as part of a music application. While also highlighting the implications for current treatment interventions and longitudinal experimentation designs. Boulanger [9] suggests using music technology to understand and enhance the brain's plasticity, learning, and memory, emphasising the importance of structuring experiences to efficiently and consistently target biological mechanisms for better health. Based on Boulanger's findings, there is also a whole interaction paradigm that comes to light in the creation of such novel music applications for ASC intervention that she finds equally essential to discover through integrating subjects within a collaborative design process.

Especially the collaborative aspect emerges in Boulanger [9] report as one of the key aspects for future research. The goal of facilitating social interactions through music interactions is to be achieved through the use of a broader creative environment for the given melodic contour and embedded rhythm tasks. Ideally, such a system would provide an alternative platform for musical co-creation, allowing individuals with ASC to engage in collaborative music-making without relying on direct social interaction. An approach Boulanger [9] argues potentially could alleviate symptomatic social behaviour associated with ASC. Shifting the experience from a potentially isolating social microcosm to a supportive atmosphere could encourage socialising behaviours such as joint attention, social timing, cue reading and social perspective. Suggest further investigation of avatars' usage to support social interaction beyond musicking. Alternatively, a designated super-user role could prompt subjects to interact with each other or acknowledge each other's contributions, thus enhancing the social experience. By understanding these approaches' potential benefits and limitations, we can design more effective and engaging social experiences that encourage socialising behaviours and promote a sense of community among participants.

Music therapy has been shown as an effective clinical intervention to improve verbal and nonverbal communication skills. As suggested by Provenzano [61] in correlation with Boulanger [9], it has been found that music therapy activates different brain parts to work on developing communication skills, such as music and language sharing overlapping characteristics such as tempo and pitch. Johnston et al. [38] found that music therapy interventions that involve active and improvisational techniques demonstrate exceptional effectiveness in facilitating communication skills, promoting cognitive development, and forming social relationships. The authors highlight the significance of a participatory and cooperative design process that incorporates individuals with ASC right from the beginning. They also underscore the numerous opportunities cutting-edge technology provides to develop novel and interactive interventions for music therapy. They argue that digital advancements play a crucial role in exploring inventive methods of music interaction, stimulating children to engage with their environment creatively.

2.1.3 Movement Therapy for ASC. Closely related to music therapy, published research indicate that dance/-movement therapy (DMT) has the ability to provide both physical and psychological advantages for children with ASC. Scharoun et al. [68] underline difficulties for subjects to perform various elements of prelinguistic communication skills. Children diagnosed with ASC may exhibit difficulties coordinating their speech with eye contact, demonstrating a sincere interest in others' thoughts and opinions, and identifying the appropriate timing to initiate and conclude a conversation. Their behaviour is by Scharoun et al. [68] characterised as looking past individuals rather than engaging with them, which results in a lack of interpersonal contact, joint attention, and comprehension essential to the acquisition of language pragmatics. Children diagnosed with ASC also commonly face challenges in motor skills, including difficulties in planning, organising, and coordinating their movements. These issues may manifest as early as infancy, with difficulties properly sequencing crawling and walking. As children with ASC grow older, their motor deficits can become more pronounced and evident in basic motor control skills, such as poor coordination, difficulty with precise gestures, awkward gait, poor posture, and reduced muscle tone.

DMT promotes inclusivity and creates an environment where every child, regardless of physical abilities, can express themselves non-verbally, explore their physical self, and become an integral part of the social fabric. As movement and dance are inherent forms of communication, they serve as nonverbal means of expression for children who struggle with traditional methods of communication. The documented effectiveness of DMT was recently reviewed by Takahashi et al. [74] and, similarly to music therapy, conclude is in dire need of a more sturdy and reliable evidence-based research approach. However, Takahashi et al. [74] found that different forms of mirroring practices within DMT as an intervention for ASC have been found to enhance the social skills of ASC subjects between four and 55 years of age.

Similarly, Morris et al. found mirroring- and rhythm-based interventions [57] to show substantial results for developing communication and social skills for children diagnosed with ASC. Their systematic review suggests that these interventions are effective and well-received strategies that hold therapeutic potential. While also emphasising the importance of further research in determining the most effective duration and frequency of interventions for individuals with ASC at different levels of severity. Additionally, Morris et al. [57] highlighted the potential benefits of MDT mirroring interventions for children with ASC, as it addresses their fundamental challenge of social disinterest. Suggesting that the "broken mirror" hypothesis by Chen et al. [15], referring to the concept of a mirror neuron system that is somewhat deficient in individuals with ASC, may offer an explanation for the positive effects of mirror-based interventions examined in the review.

Simpson et al. [72] argue that ASC children are predisposed to musical stimuli, demonstrating intact musical perception despite their substantial lack of communicative social skills. Individuals with ASC often respond well to rhythmic interventions, such as dyadic drumming [73, 82], which provide a non-threatening and adaptable medium. Through rhythmic and musical interventions, ASC children have various opportunities to enhance their social skills, including imitation, joint attention, social reciprocity, shared affect, and empathy. Morris et al. [57] suggest the improvement in communication skills observed in the studies reviewed may be attributed to the child's increased attunement to their social partner through rhythmic exercises, leading to greater awareness of their partner's emotions and intentions. The studies have certain limitations, such as small sample sizes and the absence of long-term effects or generalisation to natural environments. Therefore, future research should focus on utilising mirroring and rhythmic techniques in larger groups of children with ASC to determine their effectiveness in enhancing communication skills and social development in naturalistic settings.

2.2 Collaboration Through Technology for Children with ASC

This section presents a comprehensive overview of the interrelated concepts of collaboration, communication, and play for children with ASC. Yuill's [85] *Co-EnACT Collaboration Framework*, is presented, which emphasises Collaboration through Engagement, Attention, Contingency, and Control to facilitate mutual understanding. She explores how different fields define and detail children's collaboration. Psychology, education, human-computer interaction and computer-supported collaborative learning investigate children's collaboration. Her objective is to underscore the interconnectedness of the aforementioned fields in her book called *Technology to Support Children's Collaborative Interactions*.

Alongside presenting her findings, we intend to explore further the mechanics of collaboration by extending Yuill's point of view with principal research from the HCI community, especially from fields such as shareable interfaces and embodied interaction. This way, we bring versatile technical understanding on designing collaborative experiences for children, with empirical learnings, to inform our thesis more directly. Continuing the previous chapter's review of therapeutic practices for autism spectrum disorder, we aim to highlight the specifics and differences regarding collaboration for children with ASC. We also present how communication as a part of collaboration can serve as a key obstacle for some children with ASC and show how this gap in collaboration can be enabled through innovative technologies designed by the HCI community.

2.2.1 The Mechanisms of Children's Collaborative Interaction. Examining the phenomenon of collaboration from its earliest roots, a good starting point is Vygotsky's theoretical perspective on how social interactions shape children's development [79]. His main psychological framework, the cultural-historical activity theory developed in the early 20th century, was ahead of his time in suggesting that social, cultural and tangible tools highly shape children's development. Yuill proposes that the Vygotskian view of cultural artefacts shaping children's mental development can be connected to modern digital technology's impact on their advancement [85].

Children arrive in a world where everything around them is already constructed. Social norms, laws, physical objects and technology are already designed, and as the newest component of this system, children need to adapt to this pre-constructed world through their development. Thus, this explicitly shapes children's thinking and frames how they navigate their progression through continuous interactions [85]. The zone of proximal development (ZPD) is crucial for successful early progression. ZPD is the difference between children's momentary level of development and their next-to-reach level [79]. In this zone, the learning process is a collaborative effort guided by a parent or caregiver in a social context. Ultimately the child learns a specific skill by trial and error, based on the dynamic feedback and guidance provided by their caretaker, such as walking, tying a shoelace, or peeling a banana [79]. This is illustrated as scaffolding by Wood et al. [80], where individuals with more senior experience dynamically adapt and gradually decrease support while supporting children to learn specific tasks. Manifesting a theory that children's development starts as an inter-psychological phenomenon before turning into intro-psychological—before they successfully carry out tasks independently.

Influenced by Vygotskian theory, Yuill introduces a novel collaboration framework between children and thoroughly explores its relationship to technology in her book. The Co-EnACT framework stands for Collaboration through Engagement, Attention, Contingency and control to support understanding Together. Based on the framework, she defines co-located collaboration as follows: *"it involves shared engagement in an activity with mutual attentional focus to co-create and maintain a shared understanding of the activity dynamically, pursued in ways that enable synchronised and contingent actions through shared control"* [85]. In the following paragraphs, we unpack the Co-EnACT framework into its steps: Engagement and Joint Attention, Contingency and Control and Shared Understanding. We will provide additional examples from HCI research to highlight how technology can facilitate these particular steps and how design can act as a transitional medium between stages of collaboration.

Engagement and Joint Attention is the primary aspect of the collaboration process. Parten's original engagement framework, revisited by Robinson et al., can be placed in juxtaposition with Yuil's model of collaboration mechanics [66]. Based on thorough empirical data gathering for months in nursery homes, the authors observed children's open play and analysed their observations. They came up with five categories for engagement based on social participation in cooperative play [66]:

(1) *Solitary participation*: The least engaged state is when children play completely alone and do not even acknowledge the presence of their peers.
(2) *Onlooker participation*: In this state, children are engaged, and they pay attention to their peers' play, but they do not get engaged proactively. Nonetheless, this onlooker participation is undoubtedly valuable for children—especially younger ones, around 3-4 years old—as they can reflect on the current play situation and get comfortable with it.
(3) *Parallel-aware participation*: Compared to onlooker participation, children play with each other side-by-side, but their actions do not directly influence each other. All parties are aware of each other and their play, but they do not intertwine the narrative of playing together. Most of the time, they are also mindful of each other's awareness, which mostly happens in the visual domain. Still, other modalities, such as auditory or tactile, can be a channel of perception.
(4) *Associative participation*: In this phase, children actually play together but without a clear, coordinated arrangement. They exchange information, ideas and toys or tools with each other and share their thoughts.
(5) *Cooperative participation*: Finally, the cooperative play describes the relationship when children play together and establish a set of norms and roles. They have a shared understanding of the play scenario and identify a common goal they "play" towards.

Collaboration Mechanism	Engagement	Shared attention	Contingency	Shared understanding
Solitary participation	No	No	No	No
Onlooker participation	Yes	No	No	No
Parralel-aware participation	Yes	Yes	No	No
Associative participation	Yes	Yes	Yes	No
Cooperative participation	Yes	Yes	Yes	Yes

Table 1. Robinson et al.'s engagement model in juxtaposition with Yuill's Co-EnACT framework

The Co-EnACT framework aligns well with the above-presented engagement framework, as seen in Table 1. To facilitate children's collaborative play through technology, the transition between different play states is particularly interesting. First, identifying these transitions and then being able to aid these transitions through design can lead to higher levels of engagement in collaborative play [85]. Technology can be an efficient tool for optimising collaborative interactions and be a prompt to push children in-between different collaborative states of play fluidly. In the next section, we focus more closely on how to design shareable technologies to aid this collaboration process between children.

2.2.2 Technology to Facilitate Children's Collaboration. Following the previously presented taxonomy based on Robinson's levels of engagement in collaborative play, we connect Hornecker et al.'s work about technology's sharable capabilities to identify means of transition between levels [34]. It is important to note that these transitions between levels of engagement are not explicitly carved out; they are somewhat fluid and continuously exchanging. Thus, connecting the shareability model does not entirely match the transition states between engagement levels. Still, it proposes valuable insights about designing an ideal flow for shareable technologies.

Two main concepts define shareability according to Hornecker et al.:

- *Entry points:* How can we design technology to invite people to engage with a group and induce temptation for interaction?
- *Access points:* How can we design affordances that prompt people to get involved and interact with a group's activity?

Hornecker et al.'s model of shareable interfaces is shown in Figure 1. The diagram reflects the temporal quality of the interaction flow from left to right, as perceiving entry points define the access points of the interaction. *Overview* in the intersection is necessary to determine how and what can be done with the technology and the system's affordances. This can also be obtained through watching others interact with it. This can also lead to luring users to approach a piece of technology via the *Honeypot Effect. Minimal barriers* aim to convey a simple mental model where users can easily go through the entry points. *Perceptual access* allows understanding the group dynamics and prompts people to join ongoing collaborative interactions. *Manipulative access* provides handles with which the system can interact directly. Finally, *fluidity of sharing* describes how actively users can interact with each other, change their roles and leave or pick up tasks. Figure courtesy of Horenecker et al.[34]

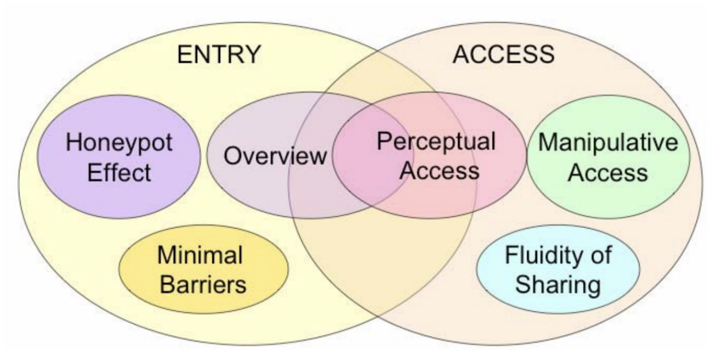

Fig. 1. Hornecker et al.'s model of shareable interfaces

Now we can look at how designing for shared interactions by Horenceker et al. can influence transitions between the previously introduced modes of engagement by Yuill [85].

Transformation from Solitary to Onlooker Engagement This can be connected to the concept of entry points. To grab the attention of a neutral onlooker, ambient technology needs to provide a comprehensive yet not too overwhelming overview of itself. For this, an Overview or point of prospect is pivotal, especially for children who might not be familiar with various technologies and their unique capabilities. It is beneficial to observe their peers interacting with a collaborative system; children can gain a lot from being onlookers in such situations, helping them to immerse themselves more and more in the collaborative process. According to the empirical observations by Yuill, it can be advantageous to incorporate already familiar objects in the interface [85].

Another aspect of entry points helpful in transitioning to onlooker engagement is the Honeypot Effect. Hornecker refers to the Honeypot Effect as a progressive lure with a social effect, enabling people to mingle in the near proximity of an interactive technology after getting drawn to it. This can also be a self-generating effect of collaborative designs as more and more people gathering around results in a spike of interest in bypassers. Also, the Honeypot Effect can be applied temporally, as well, by incorporating progressively more engaging interactions throughout an interaction flow [34]. The Honeypot Effect can be purposefully facilitated via different sensory domains. The visual domain is usually utilised for this; however, implementing audio cues, such as spatial sound, can also achieve significant effects [85].

The last entry point, Minimal Barriers, is quintessential to engagement. If Attraction is not established from the get-go, or other obtrusive design patterns emerge while further interacting with technology, the setup phase is cumbersome; then initial engagement is less likely to form in end users [85].

Transformation from Onlooker to Parallel-Aware Engagement This shift can be associated with Hornecker et al.'s Access Points, describing the phenomena which set up two or more individuals to join and actively participate in a group activity, resulting in one or more participants becoming aware of each other's presence. Perception and Manipulation, as part of access points shown in Figure 1, can prompt people for active involvement after their initial approach.

Perceptual access is essential to grasp what others are doing already with a shareable interface during co-located collaboration. Continuously monitoring others' actions and reactions based on the technology's inputs and outputs helps users to understand the activity and to join later more easily. This depends on the interaction methods' visibility: as openly observable body movements to trigger actions, being able to follow an entire process of user action to evoke some change within the prototype, then openly and directly perceivable feedback of that change [34].

Manipulative access mostly depends on the type and amount of inputs for a shareable interface. There are several important factors to consider when increasing access. Distributed access points can be introduced to enable simultaneous interface control in the shape of identical or diverse handles, influencing collaboration patterns. The role of physical space is crucial when designing shareable interfaces. Simple ergonomic patterns play a role here, like reach and grab, as well as the dynamics of social norms. Such as standing around a table or device establishes a shared transaction space that can initiate more fluid social interaction [34].

Yuill argues that initiating the transition from onlooker to parallel-aware engagement through technology does not have a proper step-by-step process. Rather, it requires some trial and error, imagination, and observation to get it right [85]. Nonetheless, we argue that following Hornecker et al.'s design principles for shareable interfaces can provide a solid foundation and could initiate more interconnectedness between children.

Transformation from Parallel-Aware to Associative and Cooperative Play: The final step in the process of achieving a fully collaborative approach. Compared to Parallel-Aware Engagement, in Associative and Cooperative participation, shared dependency of actions between children is more significant. Thus, closer contingency is the key to shared understanding [85]. The final Access Point described by Hornecker et al., Fluidity, plays a crucial role in mitigating true collaboration. As they put it: *"By fluidity of sharing we refer to how easily people engaged in shared interaction with a system can switch roles or interleave their actions, handing over control, continuing somebody else's action at mid-point or inserting something into it."* True collaboration is only achieved when individual contributions are not necessarily distinguishable. Structure and constraint—or lack thereof—can morph ownership into a collaborative engagement. For example, outlining explicit territories and elements with single-ownership on tabletop collaboration can inhibit fluid sharing and interleaving actions [34].

By reviewing these various stages of the collaboration process for children and presenting complementary knowledge about shareable interaction design paradigms, we aim to inform our design process on creating a collaborative accessible musical experience for children with ASC. We need to understand collaboration, specifically between children with ASC, and how that differs from children with typical development. Moreover, how existing technologies aim to facilitate a collaborative experience between children with ASC. In the following section, we investigate these outlined aspects.

2.3 Accessible Sonic Interactions for Children with ASC

As previously explained, according to Vygotsky's perspective [79], collaboration plays a crucial role in children's development. By engaging in collaborative social activities, children acquire social cognitive skills by adapting to dynamic roles and complementing one another. Thus, facilitating collaborative behaviour for children with ASC can yield opportunities for learning which might be inaccessible for them by default [85]. According to Yuill [84], there are two main pathways towards designing technology to enhance collaboration between children. The constrained and guided method explicitly prompts children to act in a certain way to achieve collaboration while interacting with others. In contrast, the free-ranging exploratory approach allows children to find ways to interact with their peers, maybe with some rewards to reinforce specific behavioural patterns. It is essential to distinguish between verbally-expressive and minimally-verbal autistic children in this case. Several studies have focused on verbally expressive children with ASC with a more constrained and guided collaborative approach, presumably due to the assumption that verbal children with ASC can be treated with the same approaches as their typically-developing peers. On the other hand, minimally-verbal children with ASC were involved in multiple projects as well, but with a more exploratory approach through gestures and coordination [85].

2.3.1 Enhancing Collaboration Through Technology for Children with ASC. First, we will present examples and best practices for guided collaboration approaches, and then we shift the focus and review more exploratory projects in the field. However, as this project works with more verbally-expressive children, we do not cover previous work made for minimally-verbal kids in great detail. Finally, based on the previously presented section on movement therapy, we review projects using movement synchrony as an alternative approach to establishing collaboration.

Designing guided collaboration experiences usually involves some form of a tabletop experience. Multi-touch tables are popular for this purpose for verbally-expressive children. Gal et al.'s [28] research by the name of StoryTable involves pairs of children with ASC to create narratives together. After play sessions, children showed improvement in initiating social interactions and playing together with each other. A collaborative puzzle game was made by Battochi et al. [4], focusing on challenging jigsaw puzzles involving some form of movement synchrony. They ran a comparative study between an enforced collaboration version and a free-play alternative both with children with ASC and typically developing kids. The results show that children with ASC had more difficulties in coordination than their typically-developing peers. Wade et al. [77] highlight several potential benefits of using technology-based social skills interventions for ASC children and using their novel game and data acquisition platform, DOSE (Dyad-Operated Social Encouragement). They argue that previous research such as [4, 28] both rely on evaluation data collection methods after the social collaboration experience. Thus, designing a game-based collaboration application called DOSE features a framework to quantitatively measure social interactions between children with ASC and typically developing peers. Their pilot study involving 12 participants found that DOSE was engaging and demonstrated preliminary evidence of increased communication and activity coordination.

Being smaller multi-touch surfaces, tablets could induce collaborative behaviour, but Yuill argues that their size and design for personal use make them cumbersome for this use-case [85]. However, Boyd et al. [10] show promising results of using an iPad with a set of collaborative games. The game's features included synchronising actions and movement synchrony, dividing tasks between each other, and simultaneous interactions. A longitudinal study showed that as children got more familiar with each other, they adopted more natural collaboration patterns, like non-verbal communication. They also point out that it seemed unavoidable to design around one individual becoming dominant and taking the lead in most situations [10].

Guided collaboration experiences are not as common for minimally-verbal children, as stated by Silva-Calpa et al. [70] in their systematic literature review of collaborative technologies for children with ASC. The same researchers built some guided experiences for this group of children, such as the CoASD tabletop game, where users need to guide a car into a garage while they need to tackle various obstacles on the way collaboratively [71]. Their study identified a multitude of facilitated cooperative behaviours, such as requesting, responding and celebrating together. The effects of the prototype were evaluated positively by the children's therapists. The more common approach for minimally-verbal children is through exploration, as introduced previously. The use of tangible devices is frequent in this field, as the predominant form of communication here is through movements and gestures [71]. Thus, measuring collaboration and shared understanding is complicated, as that mostly happens through verbal exchange. Keay-Bright et al. [43] present a system where children can create sensory experiences like light effects by controlling different input devices, such as keyboards or microphones. They aimed to spark interest through playful open exploration rather than predefined tasks. They report some success in enabling children to make light effects together with their peers, compared to no prior willingness of cooperative activities [43].

Prior research has also focused on creating exploratory experiences for verbally-expressive children with ASC. One noteworthy example is Lands of Fog, created by More-Guiard et al. [55], an Augmented Reality Game inciting autonomous, open-ended exploration, prompting children to collaborate via rewards. It works based on a floor-projection system, where children need to catch virtual butterflies through dense projected fog with their physical butterfly net. The game has specific features and animations that only get triggered when two or more children work together in a coordinated manner within each other's close proximity. Their findings report that the frequency of joint actions requiring coordination has significantly increased through three play sessions. It is also worth noting that they utilise full-body interactions as interaction mediators. They argue that physical interactions in digital environments stress the phenomenon of embodied cognition, which can increase the social nature of gaming or playful experiences [55].

Another open-ended approach was developed by Hourcade et al., focusing on tablets as a collaborative medium [35]. They created a stack of open-ended, error-free tablet games where children can freely explore face-to-face interactions while performing a desirable activity, such as collaborative storyboard drawing, music-making or joint puzzle-solving. When comparing these digital activities to their 'analogue' physical counterparts, the authors found that digital activities resulted in more shared engagement and verbal and physical interactions. The attraction to technology provides an extra layer of social scaffolding and reduces anxiety, Hourcade et al. argue [35].

Finally, to bring in an alternative perspective based on Yuill et al.'s "shared understanding" was primarily discussed as an adherent consequence of verbal exchange through language [85]. However, shared understanding cannot be limited to this domain; it can also be achieved through non-verbal, embodied ways. De Jaegher's [18] vision of participatory sensemaking argues that social understanding does not necessarily require abstract communication skills but embodied interactions. Thus, collaboration can be achieved without language being the primary negotiation form in the cognitive domain via coordination of action in physical interactions. This ties into the aforementioned research on movement synchrony for ASC intervention, which is shown to be a practical approach in therapeutic practice to interact with non-verbal autistic individuals. In its simplest form, a therapist moves a part of their body, which the autistic individual follows, creating shared understanding through coordination. There are approaches to facilitate movement synchrony technologically and connect it to music. The OSMoSIS system is an interactive music and movement-based game that utilises the concept of movement synchrony and connects it to music and music therapy to foster communication and self-expression skills [62].

2.3.2 Accessible Digital Musical Interfaces (ADMIs) for Children with ASC. In terms of technologies that are focused around the auditory domain, there is an area of research within Digital Musical Instruments (DMIs) called Accessible Digital Musical Instruments (ADMIs), which entail specifically designed and customised DMIs created to allow the accessible use of digital music technology. Within this research realm, many directions are working with widely different accessible target groups. In a recent review on ADMIs, Frid [26] finds that the use of music technology in music therapy contexts has seen an increased focus as of 2019. With a vast field of different methods, developments and interaction forms. Out of 83 reviewed papers, Frid found a total of ten different interfaces control types: *"tangible controllers, touchless controllers, Brain–Computer Music Interfaces (BCMIs), adapted instruments, wearable controllers or prosthetic devices, mouth-operated controllers, audio controllers, gaze controllers, touchscreen controllers and mouse-controlled interfaces."* [26]. And 8.4% of the reviewed ADMIs had ASC user groups as their target population. She notes that ASC children may exhibit both hypo- and hypersensitivity to sensory stimuli, including differences in tolerance for hues and frequency bands that are outside the average range. Thus, suggesting that ADMIs designed for children with ASC should be considerate of each individual's specific sensory sensitivities. This section will present our relevant research findings within ADMIs that specifically focus on using technology and sound as a medium to facilitate different forms of collaborative interventions, therapy, and play to evolve children with ASC social abilities.

Based on the discovered research, most ADMIs created for ASC predominantly utilise tangible user interfaces (TUIs), sometimes in combination with a multisensory environment. The Reactable by Jordà et al. [39] offers an intuitive TUI for the collaborative creation of musical soundscapes. During a later study with nine ASC children [75], it was found to increase in the subjects' abilities in turn-taking, pointing to the use of physical objects to interact with the technological system as a critical factor in facilitating these interchanges. Closely related to this is the work of Nonnis et al. [59], which developed a TUI named Mazi that employs haptic and auditory stimulation to encourage spontaneous and collaborative play among ASC children. A five-week study with five ASC children aged between 6 and 9 years found that collaborative play emerged from the interaction with the system, particularly regarding socialisation and engagement.

Förster et al. [21] developed two ADMIs designed for ASC children. They created SnoeSky, which is an interactive installation in the form of a starry sky that integrates into the ceiling of a Snoezel-Room (a therapeutic and controlled multisensory environment), allowing users to "play" with "melodic constellations" using a flashlight. They also created an ADMI installation that enables users to explore a complex water soundscape through their movement inside a ball pool called SonicDive. The underlying goal of SnoeSky and SonicDive was to promote self-efficacy experiences while stimulating relaxation and activation in users. Förster et al. [21] suggest an enjoyable, direct and intuitive relationship between motion and sound for the participants. But, pointing out the need for variation, depth and complexity in the sound creation—as the SonicDive did see participants get bored after a relatively short period of interaction. A combination of multisensory and TUI can also be found in BendableSound by Cibrian et al. [16]. A system that facilitates neurological music therapy to improve the sensorimotor regulation of ASC children. Their created prototype utilises an elastic multisensory surface that plays sounds when touched. A formative study with 18 teachers found that BendableSound was a usable and attractive method for interactive technological music therapy. While in the follow-up study with 24 children, it was found to be easy to use and show potential for therapeutic benefits for the development of attention abilities and motoric skills.

Within a multisensory environment, Lobo et al. [49] created a mobile system designed to support therapists in teaching socio-communicative behaviours to children with ASC. Like the previously mentioned DOSE application by [77], Chimelight also offers the capability to track and evaluate the movement during usage—delivering metrics to quantify specific target behaviours. A case evaluation study with nine ASC children between five and fifteen years old found Chimelight to increase engagement and decrease targeted negative behaviours. Post-interviews and questionnaires with four music therapists led the authors to conclude that Chimelight effectively supports evidence-based music therapy and enables novel methods for interactive therapy.

2.3.3 Collaborative Accessible Digital Musical Interface (CADMI). As previously noted, a surge in research output in the design and development of Accessible Digital Musical Interfaces (ADMIs) is evident from Emma Frid's review [26]. Given the diverse needs of specific user groups, the study highlights the importance of including user participation, iterative prototyping, and interdisciplinary development teams in the design process. While the review concludes that it is not feasible to establish universal design guidelines for ADMIs, a focus on user personalisation is a crucial starting point for creating relevant and impactful ADMIs.

In a previous work of ours [37], we focused on extending collaboration as a critical aspect of the development of ADMIs. We introduced the term Collaborative Accessible Digital Musical Interface (CADMI) to highlight the significance of cooperation in creating meaningful technological experiences for accessible user groups. Our research product, DuoRhythmo, enabled people living with Amyotrophic Lateral Sclerosis (PALS) to create music collaboratively in real-time, even when physically distant [37]. This provided a firsthand experience of the joy of musical co-creation for people with limited physical abilities and motivated us to explore the possibilities of CADMIs for other target groups, such as neurodiverse individuals.

Including PD methods, which involve actively involving users as co-designers and informants in the design process, is a fundamental future research approach within the field of ADMI [27]. This approach is based on the idea that users are experts in their own needs and experiences, and their involvement in the design process can result in more relevant and usable technologies [7]. In the context of ADMIs, PD can ensure that the technologies developed are not only accessible but also meet the specific needs and preferences of the target users. This can involve co-designing the interface, the control mechanisms, and the sounds produced by the technology [26]. By involving users as co-designers, the resulting technologies can be more empowering and enable users to express themselves in previously inaccessible ways. PD also has the potential to challenge traditional power structures by recognising the agency of users and creating opportunities for them to actively shape the technologies they use [7].

3 METHODS

The following section describes the methodology throughout the different stages of the project, where we familiarise ourselves with the target group of children with ASC, conduct participatory design workshops (PDW), evaluate the created prototype as a case study and interview SEN teachers. Also included is a description of tools used in terms of software and hardware for the design and development of the prototype, followed by an introduction to the project collaborators, co-designers and research participants. All in all, our thesis project aims to uncover insights into the following;

(1) **User Research**: First, we conduct three user research workshops (URW) to get firsthand experience working with a class of neurodiverse children. Trying out different PD methods and conceptualising ideas together to pursue the project.
(2) **Participatory Design**: Through three participatory design workshops (PDW), we invite a class of ASC children to join us as co-designers in the design and development of a prototype. Here we utilise fictional inquiry in a collaborative intergenerational design team to create a technological experience that combines principles within music and movement-based therapeutic practices and mechanisms of collaboration.
(3) **Children with ASD Case Study**: The result is presented through a case study for our co-designers and the teachers of the class with ASC children. This happens through a contextualised scenario where we utilise the concept of a brain break to facilitate a showcase of the prototype and employ the scale-based questionnaire of the Mobile Application Rating Scale: user version (uMARS) to gather data based on their interaction experience.
(4) **SEN Teacher Interview**: Finally, we interview the teachers of the SEN class to assess the effectiveness of the movement and audio-based experience on enhancing social abilities such as non-verbal communication and collaboration.

3.1 Participatory Action Research for Children with ASC

The diversity of autistic experience due to neurological differences is reflected in its status as a spectrum condition, with different communication needs, preferences, and strengths. According to Ward et al. [78], in order to accurately capture the perspectives of autistic individuals during PD, it is necessary to employ adaptable data collection methods to apprehend the negotiation of meaning during knowledge co-construction. Ward et al. [78] argue that an approach like this allows for a deeper understanding of the collaborative process and promotes a more inclusive design that better accommodates the needs and preferences of autistic individuals. Frauenberger et al. [23] extend this further and highlight several challenges when co-creating technologies with special needs children, emphasising the meaningful contributions these user groups often provide in design processes that include and enable their collaboration together with HCI researchers.

PD offers a framework for working with marginalised groups often excluded from design processes [69]. Autistic children are often subject to exclusion due to their communication barriers and limited social abilities [11]. To better understand the value of participation, we seek to establish a collaborative, iterative PD process, drawing inspiration from Research through Design (RtD) [**?**] that includes children with ASC during the entire process. According to Zimmermann et al., [86], RtD is a forward-looking methodology that aims to enhance the world through disruptive innovations that challenge and transform the status quo. In conjunction with PD, this

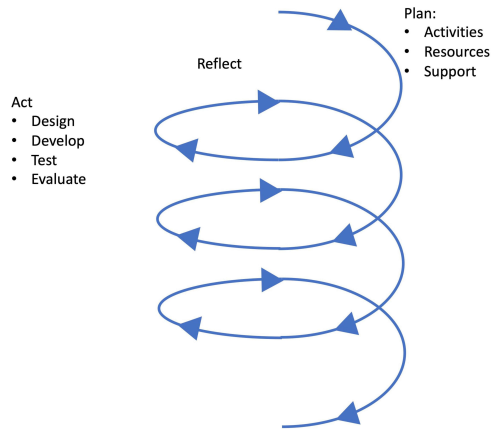

Fig. 2. Ward et al.'s diagram of iterative research progress [78]

research practice emphasises the importance of having an emphatic and inclusive connection with stakeholders, requiring researchers to be present and attentive to the needs, desires, and aspirations of those affected by the innovations being developed. This also brings forward the same suggestions by Ward et al. [78], who facilitate a PD process that they call **participatory action research**. Bringing together elements from action research with PD, as suggested by [22], which states *"PD study may be able to encourage its participants to determine and critically evaluate a range of open (and perhaps non-design specific) issues if action research principles are used."* Thus, we use action research principles, particularly as an iterative RtD model and additionally in evaluating the PD process.

To create the design and development framework, we were inspired by the work of Benton et al. [6]. Interface Design Experience for the Autistic Spectrum (IDEAS) is a method to involve children with ASC in the technology design process. The paper extends the IDEAS method to enable use with a design team. It presents a series of suggestions for optimising and organising a series of design sessions within the themes of team building, context setting, idea generation, design development, design refinement and evaluation and reflection. A similar approach is suggested by Frauenberger et al. [25] in Blending Methods: Developing Participatory Design Sessions for Autistic Children, which extends traditional research-based methods in its framework by offering a model to incorporate more context, designers' knowledge and personal information about the children in the PD process.

To guide the PD process, we utilise the concept of Handlungspielraum suggested by Makhaeva et al. [51]. It defines a conceptual space in which creative co-design activities occur and emphasises the importance of tailored conditions that enable the flexible exploration of the creative potentials of participants. It is a valuable tool for designing PD activities and balancing freedoms and structures to prevent participants from feeling overwhelmed or overly constrained. Frauenberger et al. [24] shed light on the values and qualities of having Handlungspielraum in their "Designing Social Play Things" project. We combine the iterative re-configuration of Handlungspielraum with Ward et al. [78] iterative research progress as shown in Figure 2.

Defining PD in terms of methods, formulas, and rules is not straightforward. Nevertheless, Robertson et al. [65] suggest the concept can be described as *"involving people directly in the collaborative design of the tools, systems, and surroundings that affect their daily lives."* The definition emphasises the importance of users in PD development, as they are the ones who interact with the solutions generated through this approach. Therefore, we aim to involve users and other stakeholders in the design process to the greatest extent. Which we believe will allow us to access and learn from their knowledge, experience, and interests and incorporate this into our designs. Our role will oversee and facilitate the process with our best intentions to familiarise ourselves with the diverse and complex groups of ASC children and take necessary precautions for the individual co-design participants. Ward et al. [78] argue the value of the iterative collaborative approach of participatory action research, as described in Figure 2, results in solutions that benefit from the expertise of all participants, with learning being a central aspect of the PD process and design more broadly, as knowledge is shared and co-constructed among those involved.

In the ideal PD process, all stakeholders are actively engaged as co-designers. However, Holone et al. [33] highlight several unavoidable compromises when bringing the research framework into real-life projects. Having previous experiences with PD [36], we know of several difficulties in establishing a purely authentic PD process. Even so, we are committed to the fight for inclusivity and the importance of learning from our users within a user-centred design process and allowing the user to participate in prototyping and decision-making. Our goal is to better understand the negotiation of meaning during knowledge co-construction with children while acknowledging the need for compromises in real-life projects. Ultimately, we aim to create genuinely inclusive designs responsive to all stakeholders' needs.

3.2 Fictional Cooperative Inquiry

As part of our research, the children with ASC act as co-designers. To facilitate a PD process that encompasses Handlungspielraum [51] alongside the IDEAS framework [6], we develop both workshop activities and design ideas iteratively and envelope them in an overarching narrative throughout the project phase. Similarly to the narrative framework presented by Moraveji et al. [56], we envelop the co-design process within a futuristic narrative with a specific goal and purpose that calls on the group of ASC children to act out a roleplay and access their creative minds through play and imagination. Alongside the process, we iteratively collaborate with SEN teachers and project stakeholders in the field of accessibility and interactive sound to continuously reflect on findings and establish a meaningful development phase taking into account both the children with ASC, teachers and research perspectives.

Together the goal is to envelop the diversity of ASC within the design process of a collaborative musical experience to help children with ASC be more comfortable and practice non-verbal communication and social interactions. Within HCI literature, several researchers suggest using fictional inquiry to understand and incorporate the needs of children in developing new technologies intended for themselves. Druin [20] showcases the great value of having children as research partners, creating intergenerational design teams that uncover exciting results in developing new technologies. In a collaborative PD process, it is essential to shape the context of design workshop activities suggested by Dindler et al. [19]. Considering the challenges of communication and collaboration with ASC children, a fictional inquiry framework could help bring together and onboard participants in the design process. Kender et al. [44] suggest a set of divergent creative modes when including children as designers in PD, urging to focus on *"needs and strengths of the children in their role as designers."* and using different creative modes, such as the Storyteller, the Scientist, the Actor or the Explorer, to offer ownership and engagement for the children to participate in the creative brainstorming through fictional inquiry.

3.3 Experimental Design

Our study employs a user-centred PD process to develop a movement and audio-based technological, therapeutic experience to help develop social abilities such as non-verbal communication, play and collaboration. The prototype is designed for children with ASD in SEN schools as a "brain break" in-between lectures. The prototype is evaluated through a case study with ASD children. During the case study, the prototype's perceived engagement, functionality, and aesthetics during the case study are documented using the Mobile Application Rating Scale: user version (uMARS). In comparison, the effectiveness of the experience in enhancing social abilities is evaluated based on a post-interview with the SEN teachers. Overall, our study aims to provide a novel and practical approach to help children with ASC develop critical social abilities, which can impact their long-term well-being.

Gathering data from children with ASC is never an easy task. Throughout the project, we adopt several variants to achieve reflection, discussion and connection with the children with ASC. Towards the final evaluation of the prototype, we discovered that uMARS presents an intriguing approach. However, its effectiveness in supporting children with ASC remains unexplored. In a recent study, Lobo et al. [49] deployed the uMARS-scale to gather insight from music therapists working with children with ASC. The scale offers more in-depth knowledge of technical application usage within mobile health applications. Having subscales within engagement, functionality, aesthetics, information, app subjective quality, and perceived impact offers a wide range of data points to evaluate and discuss the user experience of the prototype from a wide range of viewpoints. Still, the wording of it is more complex than the widely adopted System Usability Scale (SUS) [12]. In combination with a more in-depth method, such as the Microsoft Desirability Toolkit (MDT) [5], which measures desirability in terms of usability, it could provide a strong framework using reaction cards and elaboration methods for the case study evaluation.

However, based on our experiences throughout the project period, we found a potential drawback to adopting a more open-ended and reflective approach, such as the MDT reaction cards. Particularly during the URW, we observed that when the ASC children were asked simple questions like "How did you find the experience?" they often struggled to provide detailed descriptions. After consulting with our supervising professor and the SEN teachers at Skolen Sputnik, we deduced that the uMARS-scale might challenge the students in terms of reading and rating each question. Nevertheless, it was considered the most reliable evaluation method because, despite the complexity of the questions, they offered a comprehensive description of the given task. Therefore, after considering the factors at hand, including allowing ample time for filling out the questionnaire and providing assistance from teachers to ensure a thorough understanding of the question wording and answer options, we concluded that deploying the uMARS would be the appropriate evaluation method for the case study of the prototype.

3.4 Tools and Workflow

Creating an accessible, collaborative musical experience for children with ASC requires careful and intentional design and development choices, as previously introduced in the related work session. We create small-scale, low-fidelity prototypes for the PDW to inform our research, aid our design process, and present a wide array of existing technologies. These prototypes initially have broad and open-ended features to foster new ideas and co-creation with children. As the PD process evolves, we progressively refine and narrow down the design together with children until we reach the final stage in the project's current scope.

To facilitate the dynamic prototyping and implementation of new design ideas, we employ three specific tools: (1) Figma and FigJam for establishing the visual domain of prototyping and creating high-fidelity graphical user interfaces (GUIs), (2) Unity for front-end and back-end implementation with particular focus on iOS development, (3) and ChucK for sound design and development, a strongly-timed, concurrent, and on-the-fly music programming language.

Figma[1] is a design tool enabling real-time, highly collaborative workflows between users. It also has several other features which are highly beneficial for digital product design, such as component variants, auto layout, and advanced prototyping. The sequence of the design process started with conceptualising user or research input to tangible requirements. Next, we turned these inputs to low-fidelity sketches, then high-fidelity GUIs. At this stage, before beginning the development, small internal testing and design evaluation was performed; consequently,

[1] https://www.figma.com

the possible identified design flaws were corrected. We also used FigJam[2] to gather general graphical ideas and concepts in a mood board format.

After the design workflow, software development could begin. The technical architecture of the project was set up using the Unity Engine[3], a platform for real-time interactive content creation with highly customisable visual assets, which can be connected and modified with scripts in C# for specific applications. For the production and debugging of the developed scripts, Visual Studio Code[4] was used as an IDE. The software development aimed to follow the SOLID principles. These are software design principles for object-oriented programming, originally introduced by Martin [52]. Utilising the principles leads to developing more understandable, maintainable and flexible code. The detailed principles are single-responsibility, open-closed, Liskov substitution, interface segregation, and dependency inversion [52].

Considering the significance of sound and music in our design process, we employ ChucK[5], a programming language for real-time sound synthesis and music creation. It offers a time-based, concurrent model that is precise and expressive, dynamic control rates, and on-the-fly code modification. It is a powerful programming tool for building and experimenting with complex audio synthesis/analysis programs and real-time interactive music. Chunity[6] (ChucK for Unity) is a programming environment for the design of interactive audiovisual experiences. It embodies an audio-driven, sound-first approach that integrates audio programming and graphics programming in the same workflow. It allows programming ChucK within the Unity game development framework and directly facilitates communication between ChucK and C#/Unity.

3.5 Co-designers, Collaborators and Research Participants

The initial phase of this research project came about during the fall of 2022 after meeting Matt Robidoux, an SEN music teacher at Stanbridge Academy in San Mateo, California. Together with Stanford University's Center for Computer Research in Music and Acoustics (CCRMA) PhD student Lloyd May, we formed a group collaboration to pursue a collaborative research project within the realm of *accessibility*, *interactive music technology* and *participatory design*. Having previous research experiences within these three topics but with different target groups [36, 37], we wanted to empathise and learn more about approaching a design co-creation challenge with ASC children. Through meetings and ideation sessions with Matt Robidoux, we learned more about his class of children with neurodiversity. Based on his practice, we also learned how to plan workshops and facilitate a structured conversation with a class of neurodiverse children. We visited Matt's music class at the Stanbridge Academy several times and held three user research workshops together with his class of seven students. This formed our initial insight and understanding of how to approach ASC children using PD.

Returning from our exchange in California to Copenhagen, we entered a new project phase. We were actively looking for a Danish counterpart to designate a local collaboration partner in Copenhagen during the Spring of 2023. In this phase, we found introducing a new local partner essential, as executing PD workshops runs seemingly smoother if all the participants are simultaneously co-located in the same physical environment. As we wanted the PD process to include co-designing, showcasing and evaluating interactive musicking tools, it would have been logistically cumbersome to do remotely. Thankfully, we found a rewarding collaboration partner called Skolen Sputnik. The school has multiple locations in the Copenhagen Central Region, each specialising in different age groups of children with ADHD or ASC. Sputnik's method in the school day treatment is "Den Integrerede Indsats" (The Integrated Effort), which focuses on a limited number of students per teacher and consistency. The same well-educated adults teach the children are also responsible for addressing their social and

[2]https://www.figma.com/figjam/
[3]https://unity.com
[4]https://code.visualstudio.com/
[5]https://chuck.stanford.edu/
[6]https://chuck.stanford.edu/chunity/

personal challenges through social pedagogical treatment. Rather than having it separated, which is the norm in other SEN schools in Denmark, arguing that research has shown that forming close and developing relationships with a few adults promotes more significant learning and development for ASC children.

Affiliation	Name	Occupation	Role
Aalborg University	Balazs Ivanyi	MSc. Medialogy Student	Project lead
	Truls Bendik Tjemsland	MSc. Medialogy Student	Project lead
	Stefania Serafin	Professor	Supervisor
Stanford University	Lloyd May	PhD. CCRMA Student	User Research Workshops
Stanbridge Academy	Matt Robidoux	SEN Music Teacher	User Research Workshops
Skolen Sputnik	Mandeep Singh	SEN English Teacher	Participatory Design Workshops
	Nicklas Høg	SEN English Teacher	Participatory Design Workshops

Table 2. A list of researchers and collaboration partners involved throughout the project

We collaborated with the Vesterbro branch, having two teachers, Nicklas Høg and Mandeep Singh, and six children with ASC between the 6th and 10th grades. Similarly to our approach at Stanbridge Academy, we also sat down with the teachers beforehand to learn more about their practices and to learn more about the students, as well. This is a significant step in PD, as familiarising ourselves with the individual backgrounds of children with ASC can help in the design process.

It is worth noting that once we redirected our attention towards the collaboration with Skolen Sputnik, we kept in touch with Matt Robidoux and Lloyd May. They offered their expertise in designing PD workshops and provided valuable feedback on our planned sessions with Skolen Sputnik. Additionally, they conducted comparable exploratory studies with students at Stanbridge based on our suggestions. This was a valuable opportunity for us not only to ideate but put these into at a higher pace and with a broader user group than we would have been able to do ourselves. As this is not work necessarily directly performed by us, it will not be part of this report but will be used as guidance for our process.

An overview of the collaborators in terms of academic advisors and SEN teachers is presented in Tabular 2

4 USER RESEARCH WORKSHOPS (URW) AT STANBRIDGE ACADEMY

8-30th of November 2022, San Mateo, California

The idea behind the URW we conducted at the Stanbridge Academy was to get first-hand experience interacting, engaging, and facilitating a group of neurodiverse children. We worked with Matt Robidoux's high school Music Production Class, which consisted of seven children from 10th-12th grade; see description of the participants in Table 3. The children have diverse developmental and physical disabilities, such as ADHD, autism spectrum disorder, and degenerative muscular conditions. They also have varying levels of proficiency and enthusiasm for playing music. Some enjoy playing the guitar and ukulele, others prefer playing the keyboard, and some enjoy singing. Having such a diversified target group pushed us to gain further background knowledge of our target group and investigate related work in detail.

Primarily, we looked at PD methods for kids with autism spectrum disorder and aimed to connect the learnings to our project. We also tried to identify existing work in designing new musical experiences together with children with special needs. Following Benton et al. [6] IDEAS framework, we mapped out three workshops at Stanbridge Academy.

- **Workshop 1**, Meet & Greet: Getting to know students in a lecture and observing teaching methods.

- **Workshop 2**, Team Building: Enabling students into a more creative mindset through playful and imaginative ice-breakers.
- **Workshop 3**, Context Setting: Showcasing various existing digital musical experiences, thus students can grasp the feasibility and complexity of the ideas they could develop later.

The results of these workshops are reported in the next section in more detail. Throughout these sessions, we gained experience working with children with ASC and gathering small-scale mixed methods data and observations to inform the future design and development phase of creating a collaborative musical experience for kids with ASC.

ID	Grade	Condition	Notes
SA1	10th	ASC	Explorative, team player, task-oriented
SA2	10th	ADHD	Tech-savvy, bored easily
SA3	12th	Degenerative muscular condition	Eager to try new things, talkative
SA4	12th	ASC	Perfectionist, skilled guitar player
SA5	12th	Down syndrome	Social, loves singing, creative
SA6	10th	ASC	Focused, piano, sometimes absent

Table 3. An anonymised list of the neurodiverse children fra Stanbridge Academy that took part in the user research workshops

4.1 URW 1: Meet & Greet

8th of November 2022

On our first visit to Stanbridge Academy, we got the chance to sit in a lecture and observe how Matt teaches his class. After Matt introduced us to the children, they played some of their favourite songs they'd been rehearsing, and to break the ice, we played some music together, where we played the vibraphone and the guitar. During this session, we observed how the kids interacted with each other during playing and followed Matt's instructions. After the meeting, we planned the next steps with Matt and Lloyd.

4.2 URW 2: Team Building – Superheroes and Super instruments

15th of November 2022

For this workshop, we planned two exercises that could help the students shift into a more creative, "everything is possible" mindset, where their disability is not a barrier to creating something together. First, we used an icebreaker game where we promoted the students to create a superhero with a unique ability and draw a corresponding superhero mask[7]. This was used as an introduction round, where everyone presented their superhero and explained their superpower. As a second exercise, to nudge the students to think creatively in a musical way, we asked them to come up with their dream instruments, which had never existed before. The exercises helped us to get to know the students better. Moreover, we could identify some possible directions based on their dream instrument ideas. After the workshop, Matt suggested we use Google Forms to extract more information from the kids based on the session. We synthesised a series of questions based on their proposed instruments.

[7] https://gamestorming.com/ice-breaker/

4.3 URW 3: Context Setting

30th of November 2022

For this workshop, we wanted to showcase various existing digital musical experiences, so students could grasp the feasibility and complexity of the ideas they could come up with. We chose two examples from the Chrome Music Lab by Google[8] Shared piano and Kandinsky. Unfortunately, Kandinsky did not work on the children's iPads, so we swapped that for Melody Maker.

We instructed the children to try the Shared Piano experience together, as we were curious about how a digital collaborative musical experience works in this setting. We identified various interesting patterns of co-creation. Some children instructed others to play a certain way, whereas others found it fun to create intense musical sequences. We asked the students to reflect on the experience afterwards and point out specific aspects of the knowledge they liked or wanted to change. They said playing music with the class as an open collaboration was fun. However, they were overwhelmed by creating sounds directly played back for the whole class.

On the other hand, we asked them to play Melody Maker on their own and share their experiences afterwards. They preferred composing beats on their own and enjoyed how simple it was to come up with musical ideas in a rapid way. We also observed that during playing with this experience, the students were more focused and in the flow.

4.4 Insights & Reflections on the URW

Neurodiversity is vital to consider in user research and design. By working with a group of neurodiverse children, we gained valuable insights into how to interact and engage with this specific population. Utilising PD methods throughout the workshops, we applied playful and imaginative icebreakers to help the students shift into a more creative mindset. This approach can be beneficial for engaging children with ASC who struggle with traditional teaching methods. In planning these, we learned that it is essential not to be too attached to the plan. Because if there is one thing we learned, nothing will probably go as planned while conducting creative workshops like the ones we held during the URW, when having ASC children as participants. They are wonderfully diverse from ourselves, and the aspect of neurodiversity brings a new spectrum of different ideas and challenges.

Contextualising the design challenge can be a supportive method to engage the students and help them understand the feasibility and complexity of the ideas presented. In URW 3, presenting existing digital musical experiences helped the students grasp the project's potential and inspired them to think creatively about how they could contribute to it. Through the feedback given and observations made during this session, we better understood the student's abilities and interests, which will be used to inform the design of future workshops and the development of the collaborative musical experience. While working with Matt's class, we also grasped the incredible diversity one has to take into account, which was challenging at times. Asking simple reflective questions such as, *"What did you think of this experience?"* was often met with complete silence, and we understood that this was an important aspect to consider for future workshops. Still, the experience was gratifying. Overall, the workshops provided an opportunity to gain first-hand experience working with a neurodiverse population and use PD methods to engage children with ASC.

- **Importance of Observing and Getting to Know the Target Group**: The first workshop (URW 1) allowed us researchers to observe how the children with neurodiverse conditions interacted with each other and followed instructions. This helped us better understand the student's capabilities and needs, which informed the design and development of the following workshops.
- **Creativity and Playfulness as Facilitators**: During the second workshop, URW 2, we focused on team building and encouraging the students to shift into a more creative mindset. We used an icebreaker game to encourage the students to create a superhero with a unique ability and draw a corresponding superhero

[8] https://musiclab.chromeexperiments.com/Experiments)

mask. This exercise helped the students think creatively and develop their dream instruments. Playful and imaginative exercises can facilitate creativity and help overcome barriers posed by disabilities.

- **Digital Musical Experiences for Collaboration and Individual Expression**: In the final and third workshop, we showcased digital musical experiences such as Shared Piano and Melody Maker. The Shared Piano experience allowed the students to create music collaboratively, while the Melody Maker experience allowed them to create music individually. The students enjoyed both experiences, but they preferred composing beats on their own and enjoyed the simplicity of coming up with musical ideas rapidly. Thus, digital musical experiences like those presented can provide collaboration and individual expression opportunities.
- **Importance of Gathering Feedback**: After each workshop, we did our best to gather feedback from the students to identify what aspects they liked or wanted to change. This was widely different from previous experiences with different target groups, so expectations with the amount of feedback given need to be severely cut down. But, what we managed to gather helped refine our approach and tailor the subsequent workshops to the needs and preferences of the students.

5 PARTICIPATORY DESIGN WORKSHOPS (PDW) AT SKOLEN SPUTNIK

Once the URW was conducted and analysed, we planned a series of participatory design workshops (PDW). Whereas the URW mostly informed the project's theoretical background and shaped our understanding of children with neurodiversity, we carried on to create a workshop structure that actively leverages co-design processes and participatory feedback-based prototyping. PDWs are an increasingly popular method to engage end-users in developing technology products. Our series of PDW are specifically tailored to meet the needs of neurodiverse children, with a focus on understanding their unique perspectives in terms of technology preferences and generating innovative ideas for technology prototypes. Through tech demo sessions and design thinking role-play sessions, the workshops aimed to provide a platform for the children to express their views and opinions in a safe and supportive environment.

ID	Grade	Condition	Notes
S1	8th	ASC	Talkative, fixated on gender
S2	9th	ASC	Engaged, taps out, skilled drawer
S3	8th	ASC	Tech-savvy, talkative, interested
S4	8th	ASC	Shy, curious, reflective
S5	10th	ASC	Orderly, well-behaved, engaged
S6	10th	ASC	Not engaged, fixated on phone

Table 4. An anonymised list of children with ASC research collaborators during the participatory design workshops

In close coordination with the staff of Skolen Sputnik, we synthesised a workshop structure. We learned from our URW that conducting the workshops earlier would be preferable, with a longer duration and a break in between. Based on their schedule, the faculty suggested we would be allocated 10.15 to 11.45 on Tuesdays as part of their English class. To recruit volunteer students, we created a flyer, shown in Figure 3, that was printed and handed out in class about a month before we met the first time. The student's participation in the workshops was entirely voluntary. The teachers had chosen a class of students they believed would have the most stable participation rate and consisted of students who might find joy in participating in the research. The schools' approach to class participation is quite open; therefore, we were told there would be a maximum of seven students present, but probably around four to six students more often. This meant we had to create a workshop structure allowing dynamic alterations regarding how many students would partake on any given day.

5.1 PDW 1: Context Setting & Technology Review

11th of April 2023, Vesterbro, Copenhagen

In the first workshop, we put a lot of emphasis on creating a narrative structure. This decision was made based on suggestions for conducting workshops with neurodiverse children by reviewing related literature [51, 56], especially concerning our experiences during the URW. A narrative was created to facilitate our research goals, grab the children's attention, and put them in an "anything is possible" mindset. As one of the researchers could not participate in the first workshop, we created an introductory pre-recorded video that presented the narrative and played for the children at the beginning. Afterwards, three technological experiences were introduced, followed by a written reflection task. To avoid disturbances, we decided to keep the session away from external screens and technologies to limit attention drift and capture their pure experiences and preferences while interacting. To play into the narrative-based table-top roleplaying experiences, we printed five pages for each student that were put together into a pamphlet.

As presented in Appendix A, we designed the pamphlet to have a futuristic look to enhance the narrative further. Here each of the kids would be able to see the agenda of the day, read about the narrative at their own pace if the video and not effectively convey the message and be given a set of reflective writing tasks to be filled during the workshop. We hoped the idea of the pamphlet would help the children to immerse themselves in the narrative and become more engaged with the activities. After the technology demos were completed, the children were given time to reflect and share their thoughts and feelings with the group. A task not easily performed by neurodiverse children, but combined with the written feedback, it gave us valuable insights into their preferences and helped us tailor the following workshops to their interests. We held a break before concluding the workshop with a characterized roleplay session to create three conceptual design ideas for collaborative musicking.

Fig. 3. Flyer used to recruit students from Skolen Sputnik

5.2 Process

The workshop took place in a classroom at Skolen Sputnik on the 11th of April between 10:15 - 11:45. The goal was to present a series of technologies to the kids and facilitate an ideation session based on these through a roleplaying narrative. Six out of seven children from the class were present.

5.2.1 Narrative. Before we introduced the narrative, we used the same introduction superhero mask game, which we have found to work great in these scenarios as a fun and engaging activity that helps set the tone for the workshop activities. Compared to URW1, we kept a more strongly timed schedule to ensure we could get through the program as planned. Once the superhero masks had been drawn and presented, the researcher facilitating the workshop played the pre-recorded video to set the narrative stage for the workshop and try to make it more engaging and visually appealing than the URW. The presented narrative of the video was summarised in the distributed pamphlets in the following way:

> *In the year 2098, the AI has taken over all music production, leaving humanity without the art of collaborative music creation. You have been called upon as distinguished scientists and engineers from planet Earth to help rediscover the magic of co-creating music together. Now that you have explored different music creation technologies and reflected on what you liked about them, it is time to come together as a team and create three group ideas for prototypes of collaborative music creation. We are confident that with your collective brainpower, you will create something remarkable and possibly spark a revolution in the world of music.*

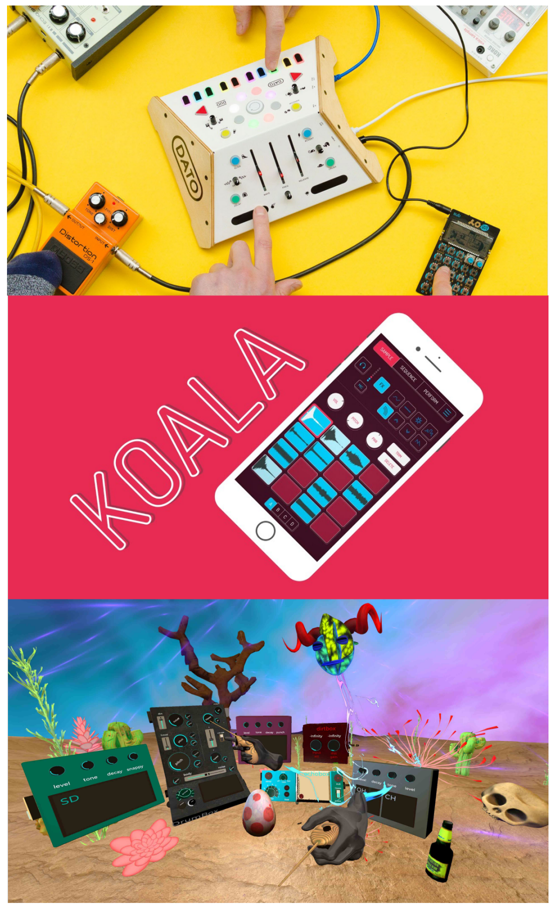

Fig. 4. From the top, we find DatoDuo, Koala Sampler and PatchXR—which were used during the tech demo

5.2.2 Tech Demo. For the tech demo segment of the workshop, the idea was to demonstrate how three different audio technologies work and allow the children to try them out for themselves. The selected three different technologies to showcase are shown in Figure 4.

After the demos, the students were asked to complete the evaluation sheets, shown in Appendix A Figure 16, to start their reflective process. There was a significant variation as to how this task suited the kids. Still, nonetheless, it provided some interesting insights regarding their preferences and thoughts about the presented technologies, especially in combination with the open discussion that concluded the tech demo review after the break. About half of the workshop was completed, and the engagement and energy level had reached a low point. So the planned break came in handy and allowed the children to rest and recharge before moving on to the next activity.

During the break, S3 preferred to continue his PatchXR journey in the VR experience. This was a comfortable medium for him to be in, and the teachers noted that he has a lot of game consoles at home and, among them, a reasonably well-used VR headset. S2 and S1 spent the entire break playing with the DatoDuo, and the two girls mainly spent time chatting on their phone devices. Toward the end of the break, the workshop researcher distributed the roleplaying cards based on which roles he felt would resonate and be close to the short impressions he had gained of the children's personalities.

5.2.3 Conceptual Brainstorming. Starting after the break, it took some time to gather everyone back to their respective classroom desks and start the explanation. The task was to participate in concept brainstorming together as a group and reflect on different ideas of how the challenge of musicking could be solved within the previously presented futuristic narrative. When prompted to read over the narrative individually, one of the teachers suggested that he read the narrative out loud for them. This led to the inclusion of Nicklas, who took the seat and "role" of S4, who had to leave the workshop to attend a therapy session.

Each participant was assigned a fictional character presented in the form of a card. Participants struggled with the roleplaying cards, causing confusion and difficulty distinguishing themselves from their roles. The activity lacked instant creativity and collaboration, with children distracted by personal connections within the group. Thus, together with the teachers, the workshop conductor had to take a more prominent place within the session than previously planned to move things forward. With the help and guidance from the teachers, the participants managed to facilitate a somewhat positive and compelling conversation between them and reached the goal of conceptualising three ideas. Alongside this, the workshop conductor synthesised the presented ideas on a whiteboard, and the following conceptual suggestions were made:

(1) **Online**: An environment where you could tap in and out of other people's soundscapes. Some form of voting-based selection to choose the current main sound.
(2) **Screen**: Shared screen experience through turn-taking and exploration together.
(3) **Headphones**: Having the possibility to access and control sound virtually. "AirDrums" playing in the air and making sounds just for yourself.
(4) **Movement**: Making sounds with your body as a "hidden" way to get exercise.

5.3 Results

The first PDW session had significant improvements compared to the URW. Having learned a lot from the experiences during the URW, we made adjustments to include better and meet the needs of the participants. The superhero mask session was significantly more efficient and worked better as a casual ice breaker compared to a more conceptual design thinking task as it was used in URW2. The participants were also prepared for the session well in advance and voluntarily participated. This was starkly compared to the URW, where we had showed up somewhat unannounced, and participation was part of their already well-beloved music class. Also, having the session earlier in the day and twice as long with an included break seems to be a lot more effective in getting the participants engaged and onboarded to the meaning of the workshop.

Fig. 5. Image from the tech demo session at Skolen Sputnik. Showing two teachers and four children actively trying out new musicking technologies

5.3.1 Tech Demo Insights. During the tech demonstration, the participants seemed surprisingly engaged in the concept. They were eager to learn and try out all the technologies and also were able to give their peers room to navigate the space in their own time. A photo during the session can be seen in Figure 5. All the technologies seemed well perceived in their own distinct way. The collaboration between participants found a highlight in interacting with the DatoDuo. Here they switched roles and engaged in participatory musicking without any need for explanation. The station, with the app, seemed to offer participants a moment of solitude and engaged them to make and record their own sounds in their own way. This was refreshing to see, as this was the technology that we had the least experience with. Lastly was the VR headset, a fully immersive experience that transported participants into the virtual world of PatchXR, where they could experience musicking in several different ways guided by a tutorial. None of the participants reported feeling disoriented, but some had trouble following along with the instructions given in the tutorial.

Overall, the three technologies on display during the tech demo represented some novel and innovative advancements in the field of playful and easily accessible musicking technology. They demonstrate how technology can foster creativity and provide unique experiences that are commonly difficult to facilitate. The tech demo showed that musicking technology could potentially change how we interact with music. The collaborations that occurred around the DatoDuo seemed to be a highlight of the demo, with up to three participants jamming together and even dancing during the sessions. This was an excellent achievement for such a simple and innovative technology, and it demonstrated the power of technology in fostering collaboration and creativity.

Within the written reflections of the tech demo, we find several participants highlighting the VR and DatoDuo due to their novelty. S5, S2, S3 and S4 found that the VR experience was fun and offered them an enjoyable experience for musicking. S2imagined that it could be fun to play the VR experience in collaboration with someone, while S4, S3 and S5 suggested that DatoDuo was the most fun to play together.

5.3.2 Concept Ideas. The openness of the brainstorming design concept phase of the workshop did cause some confusion. Firstly, the kids seemed less engaged than before the break. Once we arrived at the ideation session, the students sat back in their seats and were assigned roleplaying cards each. Here, the process of action was not decided upon beforehand—as we had decided to approach the session as an open scenario where the kids would be allowed to determine how they wanted to proceed with the task at hand. Reflecting on these choices, we find several considerations that would be important for similar settings in the future. Firstly, the students did not physically face one

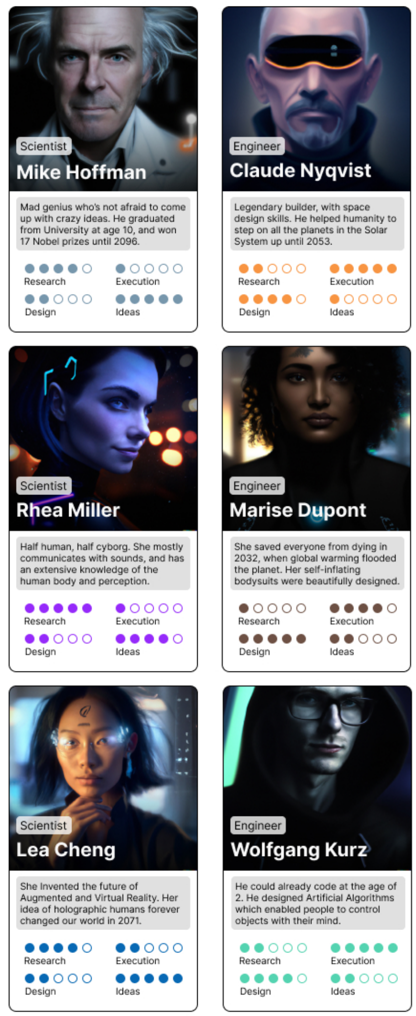

Fig. 6. Roleplaying cards used for PDW1

another, but instead, all sat in the same direction towards the blackboard. We believe this significantly impacted their ability to be present in the conversation and actively participate in the act of listening to one another. Also, the openness of the task seemed not to work out as intended. It appears that there needs to be a clear set of tasks at hand for them to be able to approach the ideation effectively. This was also emphasised by the teacher afterwards, that if the task is to open, they quickly get lost in deciding what to do. This is not necessarily limited to children with neurodiversity but is a general aspect to remember.

The roleplaying cards' descriptions and images confused some participants, and it seemed they had difficulties distinguishing between themselves and their roles. One participant stated, *"Do you have to like act like the character we got—it says she mainly communicates with sounds—does that mean I have to like to stop talking and only make sounds?"*

The activity did not seem to have an instant spark of creativity and collaboration among the children, but rather a state of confusion and some attention divergence from the task at hand. After going over the narrative together, S3 noted *"It is almost like Star Wars, but it's like a TV show. So every time you come back to an episode, it says previously on Star Wars"*. While S1 asked several questions about the goal of the workshop *So what is the goal? Is that like an AGI (artificial general intelligence) or something?*. After explaining the concept again, the process was compared to *Is this like a DnD (Dungeons and Dragons) game?* Leaving it up to the participants to decide whether to be a team confused, and there needs to be a clearer line between what is expected to get the kids on board with the process and the idea of the workshop. Having Nicklas part of the brainstorming session helped lead it forward but also made him set the starting point for a lot of the ideas. Having leading questions from the workshop conductor also made the ideas less original. To start the reflection, Nicklas told about the DatoDuo *"This was really fun, especially when you were playing together two people. And imagine if you could take this concept to an iPad screen. Where you would have like a split screen, so one person could control one side of each of the iPad. Maybe we could have both be able to control but also have it to be optional. Allow a co-creator to control the whole iPad. (...) Allow people to watch, but also allow people to join the creating."*

At this point, it was somewhat of an awkward standstill in the workshop. The teacher talked mainly, and the children had difficulties joining the conversation. Here, the workshop conductor asked one of the teachers if we could bring some Lego boxes to the classroom to see if this would help the creative process. Incorporating Lego into the session should have been planned from the beginning rather than added as an afterthought during the workshop. With Nicklas leading the word, the group continued to reflect on the possibilities of having a streaming version of the iPad idea. It would allow the discovery of new music and the inclusion of famous DJs or composers that you could join and jam together with while also enjoying the "show" that the DJ and guests put on for the rest of the stream.

Suddenly, S3 enters the discussion and says: *"Oh, I have an idea. Instead of using, you know, old music CDs, you just use DVDs and remix music in them. DVDs, like movies. Like Shrek. Just take out a part and put it together into something else."* The idea itself did not catch on with the rest of the group, but made S5 join the discussion too, and she added: *"You know, you talk about how AI has taken over music and stuff. Maybe you could make it like a game where you need to make old songs by trying to listen to the sounds and make it sound like a song that already exists. (...) Figure out the right tempos and like, put it together and recreate already existing music."*

As the session continued, the workshop conductor suggested that we together list the ideas on the blackboard to summarise and get an overview of what had been suggested so far. Bouncing on S5's idea of a game, Nicklas added to his previous collaborative iPad streaming idea: *"There could be an element of competition. Where like you could vote people out of the session if the crowd did not like it. Vote kick, where it could be optional in a room like that."*. Which in turn, by S5, was likened to a game called Monster Island[9].

[9]https://cphgamelab.dk/en/generiske-laeringsspil/klasserumsspil/

The idea of a split screen seemed to resonate with many participants, as they enjoy that part of hanging out with a friend and sharing an experience together on a split screen. And having a set of buttons and controls that belong to each of the players is a nice way to distribute the responsibilities of the experience. S1 clarifies the split-screen concept; *"I'm thinking that it would be just one screen, where you have control of this part, and I have control of the other part."* Before quickly questioning himself and saying he does not know and he's not an expert on these kinds of things. Nicklas then joins in again and suggests *"And then it would be nice if you could add your own vocal samples, where it's like—Hey, I've actually just sung this thing that I think sounds quite—and then allow the user to loop that into the mix."*

This led the discussion onwards to the topic of headphones and air drums. Prompted by the workshop coordinator, we reflected on the possibilities of bodily experiences. That would include sensors or tracking of the body to produce sounds. Nicklas suggested that it could be interesting with a solution that gave the user the possibility to play an "air" based instrument, and it would record a user's movement and produce sounds based on it. This was quickly shot down by one of the students: *"That's just stupid. The point of playing music is so that people can hear it."* When the teacher tried to argue that there might be people, fellow students or neighbours at home who would appreciate not having to listen to someone else play the drums, he had difficulty seeing the point in being considerate about the noise you produce. This led to a longer discussion that came back to the streaming experience, where one could subscribe or tap into each other musical worlds. If you preferred silence, that was utterly okay—but if you wanted to explore what other people were making, you could allow a user to enter your soundscape.

S1 had a hard time accepting ideas that he could not see being put into the world as of right now, often arguing that this or that idea is impossible. After a while, he came to the fruition that if you could insert a special kind of chip into yourself—it might be possible. But, ending with that, if one believed this was possible, then you are probably just hallucinating.

5.3.3 Post-Interview with SEN Teacher. After the workshop, we held a post-interview with Nicklas to gather insights on how he perceived the workshop's outcome. This was partly due to the fact that Nicklas was much more familiar with the children in class than we researchers, and we hoped he would be able to reflect on some of the experiences during the workshop—which we could use to understand what worked well and what could be further optimised for the future workshops.

Firstly, Nicklas was impressed with the success of the intro game of the superhero mask. He could quickly tell that as this was presented to the class—some of the students were quite flabbergasted. But once the concept had some time to sink in for all the students, he was impressed with its effectiveness in establishing an introduction to one another. Noting a form of a surprise that all six children made their own mask, and five could present their superhero mask and power to the rest of the class. This kind of started the workshop with a successful experience that quickly led them onward to the tech demo.

He considered the three different technological experiences that were possible to try out for the children to be of their liking. Nicklas said that it was a fun element, and he saw how the three girls in class had a moment of coming together through a jam session with the DatoDuo. It was interesting for him how the smartphone and DatoDuo were so accessible and how they, with minimal instructions, could, with the push of a button, easily create something musically that they enjoyed. This made him note that *"I thought they were much more playful than I would have imagined (...) They were even sitting together and laughing."*

In terms of the final part of the workshop, the conceptual idea generation, he said that at this point, it was clear to him that some of the students had reached a maximum of what they were able to digest mentally—noting some internal difficulties within the group of students and that there is generally a lack of social abilities in terms of understanding and accepting the needs of other students. This may lead to situations where students have their social boundaries overstepped, which again may lead them to leave the class and seek time for themselves.

6 PDW 2: PROTOTYPING

18th of April 2023, Sydhavnen, Copenhagen

We proposed conducting PDW 2 at our university campus to the SEN teachers at Skolen Sputnik, which they enthusiastically embraced as an exceptional opportunity for the children to experience life on a university campus. It would also provide them with a unique break from their daily routines. The teachers believed that visiting a research lab and meeting professionals dedicated to advancing science would leave a lasting impression on the children. Thus, PDW 2 was a threefold scenario where we; (1) showed them around in the Multisensory Experience Lab, (2) conducted PD workshop activities in the Augmented Cognition Lab, and (3) rounded up by trying out different haptic and audio-based research project prototypes presented by fellow researchers in the lab.

Considering the teachers' motives, we sought to seamlessly integrate the visit into the established narrative of the PD process presented during the conceptual brainstorm of PDW1, where the students had been given a role-playing character and tasked to submit an idea about how to save the future of musical co-creation to an intergalactic design contest. We informed that between PDW 1 and PDW 2, a talented team of scientists, being ourselves, had worked hard to turn their ideas into reality between the two sessions, and now we needed them to help review and give feedback on the developed prototype.

6.1 Design Concept

Before the second workshop, we synthesised insights from the first workshop into a series of design goals that we determined based on the timeline of our project scope and relevant in terms of suggestions from the reviewed state-of-the-art research within interventions for social abilities for children with ASC. Based on the discussion after the tech demo of PDW1, we found several interesting aspects surfaced during our reflection on concept ideas for the prototype. We hypothesised that a possible direction would be to include a form of movement and play between prototype users to enhance collaboration. This idea of movement was also mentioned during the discussion of PDW1, where S1 said that he thought that an experience that kind of tricked you into a form of bodily movement would be attractive for him—as he was not very fond of physical activities. So this combination of movement to control a computer system resonated with the group, as they often held breaks in-between classes that were either composed of playing Nintendo, crafted bracelets in the creative room or browsing by themselves on their smartphones.

Throughout the first half of the project, we held several long discussions as to where the experience prototype should take place (indoors, outdoors, during class, during breaks etc.), in what context it should be deployed (teacher facilitating, solely driven by the children etc.), for what duration and with how many participants. Based on our discussions during and after the URW with Matt from Stanbridge Academy and Lloyd from CCRMA, Stanford, the concept of a "brain break" came to light as a possible area to work with. Matt often found that his class came to these points in time where everything fell to the ground, motivation was gone, and he would have difficulties getting the students engaged. Nicklas from Skolen Sputnik also mentioned how several of his students have quite limited physical activities in their day-to-day life. Based on our observations, we also saw the importance of having a break within classes during our session at Skolen Sputnik. This was not the case at the Stanbridge Academy, and we saw first-hand how this could affect the presence and participation of the students in class. Matt's idea of the brain break was to create an experience that would give the students a breather, allowing them to recoup and energise for more school work. We mentioned the concept of a "brain-break" during the post-interview with Nicklas—which he found to be interesting, and he explained that it would conceptually be essential to have the possibility to tap in and out of the experience without too much effort. Thus, keeping in mind that it must be possible for the students to exit the experience without any necessary repercussions that would arise from the technology.

Following the conceptual discussion about incorporating body movements into music creation, we recognised the potential of using embodied control of musical parameters as a fun and rewarding approach, in line with the principles of movement therapy discussed in the related works section. Inspired by this idea, we developed two basic prototypes to explore how children responded to modulating sounds through their movements and gestures. Based on these considerations, we drafted the following low-fidelity prototype design goals that we wanted to develop and prepare for the PDW 2 workshop.

6.1.1 *Prototype Design Goals.*

Cardboard Prototype (to test the collaboration metaphor):

(1) Enhance collaboration: The prototype should encourage collaborative interaction between users.
(2) Incorporate movement and play: The prototype should involve a form of movement and play to engage users.
(3) Appeal to users with limited physical activities: The prototype should provide an engaging experience for users not fond of physical activities.
(4) Align with the concept of a "brain break": The prototype should fit into the concept of a "brain break" and provide a breather for users.
(5) Allow easy entry and exit: Users should be able to join and leave the prototype experience without difficulty.
(6) Accommodate multiple participants: The prototype should simultaneously support engagement from numerous users.

Phone Prototype (to test interaction technique for controlling sounds using movement):

(1) Enable sound control through movement: The prototype should allow users to control sounds using their movements.
(2) Provide intuitive interaction: The prototype should offer an interaction technique that is easy to understand and use.
(3) Support varied movement patterns: The prototype should accommodate different types of movements to control various aspects of sound.
(4) Test scalability: The prototype should be scalable to handle different levels of complexity and variety in sound control.

6.2 Participatory Design Workshop Activities

We found out via observations that the students particularly enjoyed playing with the sampler during the first workshop. So, based on the prototype design goals, we created three participatory prototyping exercises, where we; (a) investigated the means of collaboration between two or more children, (b) what embodied gestures they use naturally to change sonic parameters, and (c) showcased an extension of the sampler app from PDW 1 tech demo called the Tone Transfer[10], as we wanted to learn if sampling and then transforming their own voice into something more musical could be a fun way to produce sounds for the children. We drew inspiration from the gesture elicitation study methodology by Wobbrock et al. [76] for showcasing and assessing our phone and cardboard low-fidelity prototypes. This methodology is widely utilised when designing gesture or movement-based interactions, where users are presented with a function which controls an effect. After being presented with the specific function and its effect within an interface, users are asked to propose a gesture-based command to trigger the specific effect just perceived [76]. Looking through the systematic review, we found one application of gesture elicitation studies for musical application by Leng et al. [48]. Their work investigates gestural interface design for

[10] https://sites.research.google/tonetransfer

music interaction through a gesture elicitation study. They investigated simple sonic controls, such as pitch and octave changes. According to the study results, the agreement between users seemed to be generally low when defining such sonic gestures. So, in correlation with our proposed previously outlined prototype design goals, we created three participatory prototyping exercises, where the objectives, method and key points to observe were the following:

Tech Demo: Tone Transfer Application Demonstration

- Objective: Showcase and gather feedback on Tone Transfer
- Method: Demonstrate the Tone Transfer application to children, allowing them to interact with and explore its features.
- Key Points to Observe:
  - Creativity and expressiveness enabled by the application's capabilities.
  - Comparison of children's responses to the Tone Transfer application with their previous experiences with the PDW 1 sampler application tech demo.

Phone Prototype: Gesture Analysis for Sonic Parameter Changes

- Objective: Explore the embodied gestures children use to change sonic parameters naturally.
- Method: Observe and document children's physical gestures while interacting with self-made tech prototypes that produce sound based on movement.
- Key Points to Observe:
  - Types of gestures children use to manipulate sound parameters (e.g., hand movements, body motions, facial expressions).
  - Variations in gestures across different children and their preferred interaction styles.
  - Effectiveness and intuitiveness of the gestures for controlling sonic parameters.
  - Potential improvements or alternative gestures that could enhance the user experience.

Cardboard Prototype: Observing Collaboration between Children

- Objective: Investigate the means of collaboration between two or more children.
- Method: Observe and document children's collaborative activities and interactions while engaging in a specific task or creative project.
- Key Points to Observe:
  - How the children communicate and coordinate with each other.
  - The roles and responsibilities assigned within the collaborative group.
  - Any challenges or conflicts that arise during the collaboration.
  - Overall effectiveness and success of the collaborative effort.

6.2.1 Design of the Cardboard Prototype. To explore different means of collaboration using the cardboard prototype, we extended the gesture elicitation study [76] setup to more people, as we wanted to see how students could reach a consensus together and carry out that movement together while trying to find a shared gesture-based command to control a sound effect. Within this exercise, we intended to channel knowledge learnt about movement synchrony and its beneficial effects for children with ASC alongside the children's motivation. We combined the cardboard prototype with another idea brought up during PDW 1 to this experience, namely the split-screen-based interaction paradigm. To do this, we crafted a simple cardboard prototype—a rectangular box with four painted buttons in each corner—to replicate a shareable touch interface. Children could change parameters together if they held and pressed the "button" in the corner. At the same time, we on-the-fly-created audio snippets simultaneously with Ableton Learn Synth Playground [11]https://learningsynths.ableton.com to

[11]\unskip

observe how the children found a gesture or bodily movement together to replicate a simple sonic effect played by the researchers.

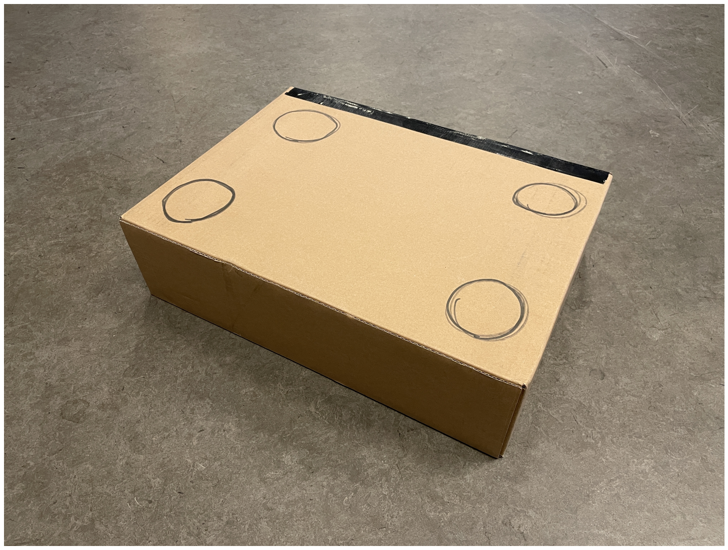

Fig. 7. Cardboard Box used during gesture elicitation study in PDW2

6.2.2 Development of the Phone Prototype. As outlined in the previous sections, we wanted to validate our assumptions regarding incorporating physical movement in the experience and utilising movement as an embodied sonic parameter controller. To create such an experience, we developed a low-fidelity prototype in Unity with ChucK responsible for the audio aspect of the prototype. We decided to use a phone as the target medium and employ its built-in accelerometer to change different parameters of a simple musical loop.

First, we connected Unity and ChucK following the guidelines of the Chunity framework. This is a straightforward process, as Chunity can be imported as a custom package in the Unity editor. Afterwards, the Chuck Main Instance script has to be attached to an empty GameObject, serving as the primary audio manager of the scene. Next, the Chuck Sub Instance script needs to be attached to the GameObject, to which we would like audio added. Finally, we can create a custom C# script to add our embedded ChucK program. It is important to note that Chuck automatically adds Audio Source components to the GameObjects, automatically enabling audio input and output.

We followed the aforementioned steps and created a C# script including a simple synth loop in Chuck called from the script's *Start()* method, detailed in Appendix B Listing 1. This synth patch consists of two main audio signal chains inside the *playTwoBars* function. One of them declared in line 9, playing a subtle bass loop in the background, consisting of a Sine Oscillator, an ADSR Envelope and Reverb in sequence. The second signal chain describes the main melody loop, and it is similar to the previous bass loop but is also a Low-Pass Filter and Delay (lines 14 and 15). In the following lines, the specific parameters of the audio components are initialised, which can be connected to direct input from Unity, as detailed further down. Finally, the main audio looping of the function takes place in lines 27-36. Here we take the *chord array* input parameter and loop through it four times, playing both the lead and the bass melody. Additionally, the position of each loop can also be set in the arguments, changing the root note of each arpeggiated sequence. In lines 1 and 2, we declare a simple major and minor scale as an array, which we use as the input parameters for the *playTwoBars* function.

As the next step, we accessed the phone's accelerometer data. We used an iPhone 12 Mini for this iteration; thus, we clarified the device's sensor capabilities first[12]. Then we decided to map various effects and its parameters to the input from the accelerometer. At this point, we did not follow any perceptual or parametric mapping techniques; we connected delay to the X-axis, reverb to the Y-axis, and the low-pass filter to the Z-axis. More specifically, movement on the X-axis increased the delay gain, and movement on the Y-axis increased the reverb gain. Changing the device's position on the Z-axis opened up the low-pass filter's cut-off frequency and increased its resonance. This process can be observed in Appendix B Listing 2, as the *AccelerometerDataHandler() method*. In line 3, we get the raw accelerometer data, which we filter to avoid unwanted fluctuations and noise (lines 6-12). This is crucial, as the noisy input could induce rapid changes in the audio domain resulting in sharp, unpleasant sounds. This is inevitably undesirable, as children with ASC can be susceptible to certain pitched sounds and noises. After remapping the filtered accelerometer input into the handpicked range of the audio effects (lines 18-22), the synchronisation finally occurs between Unity and Chuck via setting global variables in lines 25-29.

We also included visual feedback of the user's movements through the accelerometer input by dynamically changing the phone app's background R, G, and B colour values from the X, Y, and Z axes. This provided additional visual aid and representation of how the embodied sound manipulation interactions work and possibly improved learnability, lines 9-11. Finally, we included a Play/Pause button on the interface to stop and play the synth loop again easily.

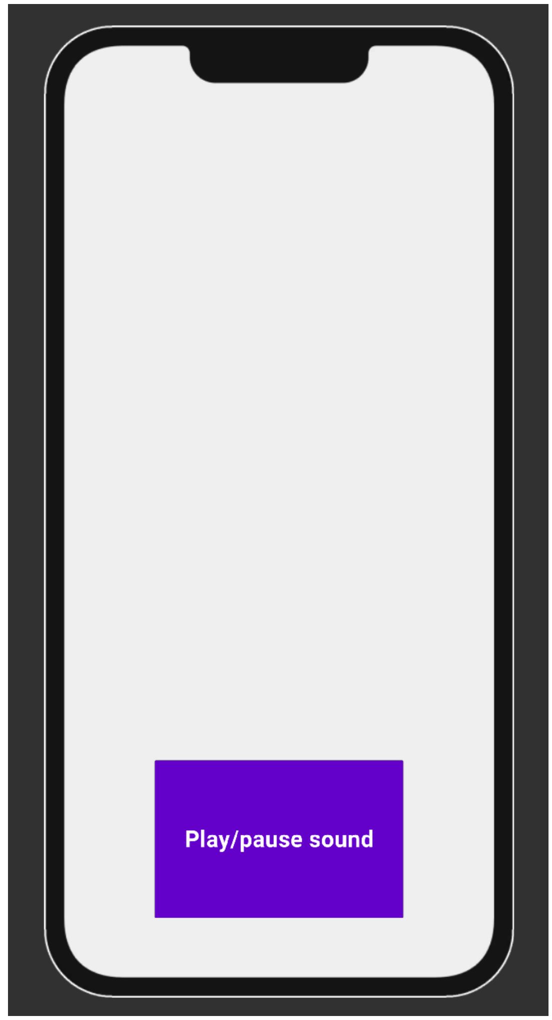

Fig. 8. Mockup of the final prototype's GUI from the Unity editor

6.3 Results

The workshop occurred at Aalborg University, where both researchers facilitated the stay. First, we gave a tour of the Multisensory Experience Lab, showing the anechoic chamber and introducing some of the areas the children could explore further after the design workshop. Once this was done, we guided three teachers and five students to the Augmented Cognition Lab, which we had been lucky to borrow for the purpose of holding the workshop.

An agenda for the day was handed out to everyone, with timeframes for each of the tasks that were planned. The students and teachers were split into two groups, and each group was assigned to either the tech demo or phone prototype for the first twenty minutes of the workshop.

[12]https://developer.apple.com/documentation/coremotion/getting_raw_accelerometer_events

6.3.1 Tech Demo Insights. The objective of showcasing the tone transfer application was to observe the creativity and expressiveness it enables. Tone Transfer is a machine learning (ML)-based program that can transform sounds into musical instruments in various styles. You can, for example, turn a violin piece into a saxophone solo. It does this using Differentiable Digital Signal Processing (DDSP). Tone Transfer uses ML to learn the tone of a musical instrument directly by extracting relationships between pitch, tone, and volume.

We wanted to learn how the children would approach the task of altering their own voice and self-made sounds to something completely different. Having observed their enjoyment of the sample application in PDW1, we wondered to what extent this would be an entertaining and engaging feature. During the session, it seemed as if they enjoyed co-creating sounds and ideating what kind of sounds one could use. One of the students made several attempts to mimic cartoon voices like Peter from Family Guy, as shown in Figure 9. While others approached the sound-making with props, using keys and water bottles. It seemed as if the best results came from softer sounds, and the keys especially resulted in a very high-pitched sound. Throughout the demo, there were several different kinds of humming and laughter.

Fig. 9. Two students try out the Tone Transfer Application

Using the Tone Transfer, there were several interesting takeaways regarding how the children had approached the collaborative musicking task. The children enjoyed and engaged during the session, particularly in co-creating sounds and imagining various sound possibilities. Thus, it seemed that collaborative musicking activity involving sound manipulation could be entertaining and engaging for children, sparking their imagination and encouraging active participation. The task of altering their own voices and self-made sounds to something completely different intrigued the children. This, in turn, highlights their curiosity and willingness to experiment with their own vocalisations and self-generated sounds, exploring the potential for transformation and adaptation. The versatility and resourcefulness of the children in utilising different objects and techniques to create desired sounds, such as the various approaches to sound-making, including attempts to mimic cartoon voices and the use of props such as keys and water bottles. Observing softer sounds and certain props, like keys, resulting in distinct sounds, provides insights into the relationship between objects and sound production. Throughout the tech demo of Tone Transfer, there was a presence of humming and laughter, indicating a sense of enjoyment and amusement among the children. These vocalisations further highlight the interactive and playful nature of the activity, where children explore and engage with sounds lightheartedly. Tone Transfer helped us shed light on the potential of technology-enhanced sound manipulation activities to foster creativity, engagement, and enjoyment among children. Understanding the children's approaches and preferences in altering sounds informs the design of our collaborative musicking experience, facilitating meaningful interactions and encouraging children's active participation in music-making.

6.3.2 Phone Prototype Insights. The main goal of the phone prototype testing was to observe the children's relation towards using embodied interaction techniques to change musical parameters. After a brief introduction and explaining the various controls of the application, the children tried it out themselves. As this prototype was not designed to be collaborative, they took turns exploring the movement interactions and observed each other doing so. They passed on the device and tweaked the sonic parameters while sitting down and performing simple hand movements. Some children spent a long time figuring out how their interactions modify sonic parameters and used simple and subtle movements. However, most of the children found it cumbersome not to gain instantaneous feedback from the prototype, especially when performing rapid movements with the phone, which was the case most of the time. Interestingly, one of the students suddenly started to spin around on his office chair while holding the phone, resulting in steady periodic sound modulation. His peers highly appreciated this, and they found it impressive.

We asked the children to reflect on the experience after they finished playing around with the prototype. Here we kept the data gathering informal through semi-structured interviews. Overall, the children found it interesting to have the ability to transform their body movements into various sound effects. However, they all mentioned that it was difficult to hear the direct sonic feedback of their movements at certain times, and the phone was not responding swiftly enough to their inputs. They suggested that how and to what extent they can change sound effects should be more apparent, and the change should happen more quickly. Additionally, one of the teachers suggested that there could be more emphasis on vertical movement and more prominent body movements. They also expressed their lack of ownership towards the actual melody constantly playing on a loop. Since we wanted to focus solely on embodied sound modulation rather than creating sounds and music during this exercise, we did not implement any controls and features for that at this stage. Therefore, participants suggested that there should be a simple and effective way to produce melodies, which would then be more fun to modulate.

After gathering general feedback on the prototype, we asked the children how they would change or extend this prototype with collaborative features. We were curious about what the movement-based musical interactions invoked in them and if they could channel their new experiences into brainstorming new collaborative features. As an initial idea, they suggested having an array of speakers distributed in space and having the phone's accelerometer control the spatial mapping of the sound on the speaker array. However, they agreed that this would not necessarily foster meaningful collaboration. The consensus regarding the collaboration dynamics was to distribute specific roles, each responsible for a different part of the composition, such as beat, melody or bass. This led to the idea of a functionality where you can freeze a beat you like and stretch it to a more extended period. One of the children suggested recording their voices, being able to stretch that, and having that as primary building blocks for a musical composition, similar to looping "gamer" music, like Minecraft. Then, after being satisfied with the recording, one could tweak it to their preference, such as changing the tempo, as one of the teachers suggested. Overall, creating or recording a sound and then modulating that afterwards collaboratively seemed to solidify as a consensual direction.

6.3.3 Cardboard Prototype Insights. After a short break, we gathered in the lab again to conduct a brief gesture elicitation study. Here the goal was to investigate and document the children's approaches to a collaborative musicking task, employing a non-technological medium in the form of a cardboard box to simulate the recreation of technologically produced sounds. We wanted to gain insights into how children recreate a series of sounds by presenting them with auditory stimuli and prompting them to envision their interactions with the box to produce similar sounds. We discovered several creative and adaptive approaches children employ when faced with the challenge of recreating complex auditory experiences.

Fig. 10. Two students try the cardboard prototype

This workshop activity served as a means to document and analyse how children approached the task of recreating a series of sounds using the cardboard box as a non-technological medium to mimic the interactions one would make to create sounds. By presenting auditory stimuli and prompting the children to envision their interactions with the box, we sought to gain insights into strategies employed by the children to recreate auditory stimuli and what type of embodied interactions come naturally to change sonic parameters for them.

During a follow-up discussion, one of the participating students shared her perspective on the workshop activity; *"It was quite funny. Maybe if we had like more time to communicate what we wanted to do, instead of just like the strongest did what they wanted to (...) Figure out what we actually, you know, felt like with the sound and maybe something more comfortable."* Thus, suggesting it was an amusing activity but also provided valuable feedback on the process. Her mention of wanting more time for communication and collaboration among the participants is interesting—as while they were partaking, there were several different approaches to how this would happen. Some would stop beforehand and discuss how to move, while others moved instinctively. But it is definitively important to consider everyone's input rather than solely relying on the strongest individuals to dictate the direction of the activity. The student also mentioned the need for a more comfortable environment, suggesting that a supportive and relaxed atmosphere would facilitate a deeper exploration of the participants' feelings and intentions related to the sounds they were recreating.

In response to the feedback, one of the SEN teachers noted to the student that *"Just want to say that, it also looks like a part of the exercise was to communicate without words. (...) Do you remember we talked about non-verbal communication? Like you also have communication without words, but using the body."* The feedback highlights the importance of creating an inclusive and communicative environment during such collaborative musicking activities. Allowing sufficient verbal and non-verbal communication time and providing a comfortable space allows participants to effectively express their ideas and contribute to the collective process of sound recreation. Considering the perspectives and preferences of all participants promotes a more equitable and engaging experience. We also learned different interaction techniques and moves the students used while recreating their sounds and could test with four or two participants simultaneously.

6.3.4 Resarch and Lab Showcase Insights. During the final part of the workshop, the participants reconvened in the Multisensory Experience lab, which provided an ideal setting for further exploration. The lab environment offered a conducive space for the presentation of various research projects by university students and two PhD students specialising in auditory prototypes and haptic technologies. The students had the opportunity to explore the anechoic chamber once again, an auditory training application for people who are hard of hearing and the intricate interplay between haptic feedback and musical output through a piece of haptic furniture, as shown in Figure 11.

Fig. 11. Students and a teacher trying out different technologies in the Multisensory Experience Lab

Overall, we received approving feedback from the SEN teachers regarding the visit to the university and the workshop. The teachers expressed joy with the opportunity to expose the children to a new and stimulating environment. The positive response suggests that the workshop effectively catered to the specific needs and interests of the children while also aligning with the educational goals of the SEN school. They also acknowledged that we had made the proper considerations in terms of the workshop's content, length, and placement, indicating that careful thought and planning were undertaken to ensure a meaningful and impactful experience for the children. By tailoring the content to suit the abilities and preferences of the children, the workshop created an inclusive and supportive learning environment. The appropriate length of the workshop likely enabled the children to remain engaged and actively participate without experiencing fatigue or becoming overwhelmed, especially compared to our experiences during the URW. By providing a new and exciting environment, the workshop engaged the children and created a sense of novelty and curiosity, fostering a positive learning atmosphere. The recognition from the teachers reinforces the value of collaborative efforts between SEN educators and university student researchers in enhancing the educational experiences of children with special needs.

7 PDW 3: CASE STUDY

16th of May 2023, Copenhagen, Denmark

The third and final PD workshop took place at Skolen Sputnik. This session aimed to understand the impact and evaluate the effectiveness of the prototype in a contextualised scenario. To achieve this, we scheduled a visit to the English lecture class on Tuesday 16th of May from 10:15 to 11:45. The workshop began with an overview of the progress made since the PDW 2 workshop. Once the students were familiarised with the prototype, we introduced the concept of creating a time capsule. The goal was to record and share this capsule in 2098, enabling the role-playing scientists introduced in PDW1 to gain insights into contemporary music creation. We intended to help them tap into the power of musical intuition and creativity. The recording of the soundscape to be sent in the time capsule narrative served as a culmination of the workshop. To assess the effectiveness of the case study, we utilised an adapted version of the uMARS questionnaire, see Appendix C. Additionally, we conducted a semi-structured interview with the two teachers. The interview explored the potential relevance, effectiveness, and impact of incorporating a prototype-like product into their regular school day.

7.1 Design Concept

An analysis of insights gathered throughout the second workshop was conducted to prepare for the third workshop. This synthesis aimed to distil the acquired knowledge into a set of tangible design goals that would guide this final stage of the project. Additionally, relevant findings from the related work the section was reviewed, specifically related to designing shareable interfaces and collaborative interactions.

The two participatory prototyping exercises conducted during PDW2 provided insights on several levels. The phone prototype evaluation showed the importance of incorporating swift and responsive sonic feedback to body movements. This could enhance the interactions' realism and playfulness. Moreover, designing more obvious sound effects could improve embodied sonic exploration.

Regarding the collaborative aspect of the prototype, the cardboard box exercise affirmed our initial preconception that one shareable tool could be a fun way to modulate sound effects together for the children. However, the main challenge in this final iteration is to convert the enjoyment aspect from a cardboard box to a sharable interface designed for the iPad. This must involve clearly defined separate play areas and intuitively designed controls for simultaneous interaction between four people.

Finally, gathering inspiration from the success of the ToneTransfer demo, implementing an intuitive yet performative live sampler and looper is necessary. As children enjoyed recording and listening back to their own voices, including a similar feature as the main sound source—as suggested by S5—would serve as an interesting base for further sound modulation. As working with sampled recordings can result in dissonant, glitchy or unpleasant sounds sometimes, an array of individual controls needs to be provided, where children can tweak their recordings and give them pleasant and musical final shape. Based on all these insights, we identified the following prototype design goals for the Case Study Evaluation:

7.1.1 Prototype Design Goals.

(1) Incorporate swift and responsive sonic feedback to body movements to enhance interaction realism and playfulness.
(2) Develop a shareable interface for the iPad that allows for simultaneous interaction by multiple users, with clearly defined separate play areas and intuitively designed controls.
(3) Implement an intuitive and performative live sampler and looper with a feature allowing children to record and listen to their own voices, serving as a main sound source for further sound modulation.
(4) Provide individual controls for children to tweak their recorded sounds, allowing them to shape and create pleasant and musical final compositions: volume, playback rate and filtering.
(5) Design obvious and intuitive sound effects to improve embodied sonic exploration.

(6) Ensure the design facilitates collaborative and cooperative interactions among users, fostering a sense of shared musical creation and enjoyment.
(7) Prioritise user experience and accessibility, considering the specific needs and preferences of children with Autism Spectrum Condition (ASC).

7.2 Design and Implementation

For this iteration, we wanted to create a more holistic vision for the prototype and design a high-fidelity experience. This is important as we observed throughout the PD workshops that the children have a high level of digital autonomy and maturity. They often play video games in their free time and use several smartphone apps for multiple hours daily. Thus to efficiently cater for a target group with such digital nativeness, it is crucial to present them with a detail-oriented and high-fidelity prototype reaching the standards of state-of-the-art applications. With this notion, and based on our synthesised learnings from the previous workshops, we started the design process by establishing an appropriate design language for the prototype.

We started the design process by arranging a visual moodboard. Here we aimed to give shape to some of the more abstract ideas and requirements we had in mind. We broke down the process into five main sections: Colours, Fonts, UI elements, Tone and Visualizer, as seen in Figure 12. The gathered inspiration directly informs the high-fidelity UI design. To cultivate a playful ambience, vibrant and contrasting colours can be utilised, evoking a sense of excitement and joy. Friendly and playful colours and shapes might establish an emotional connection with the children, enhancing their engagement and ownership towards the interface. The retro-futuristic influence can be helpful to tie the interface into the PD process narrative and base the main audio-visualiser component on this style. Furthermore, the design language could highlight the interface's resemblance to musical devices, featuring instrument-like visual cues that promote familiarity and intuitive interaction.

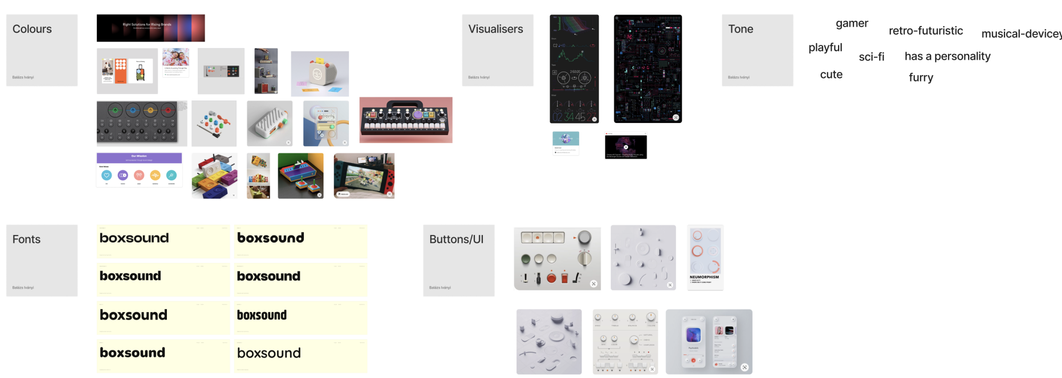

Fig. 12. Moodboard detailing alternative directions for the visual design language made in FigJam

7.2.1 Graphical User Interface Design. The main challenge when designing high-fidelity interface GUIs was providing an intuitive metaphor for shareable interactions. From the results of PDW2, we deduced that the cardboard prototyping exercise shed light on the importance of individual play areas and the ergonomic layout of the interface controls. We designed the prototype for four people's co-located collaboration by utilising the iPad's physical capabilities, allocating one player to each corner of the iPad. Thus, the most important interaction of the prototype—recording audio through the built-in microphone—had to be closely located in the corner of the interface to show its hierarchical relevance and afford a reasonable reaching distance with one finger.

Additionally, to highlight the multiplayer capabilities of the prototype, we assigned a dedicated colour to each "corner" to enhance ownership and distinguish between roles, as seen in Figure 13. Three individual effect controls correspond to the main recording button in each corner of the interface. These are touch-controlled knobs or radial sliders, colour-coordinated with matching recording buttons. These were also placed so they could be reached even with one finger ergonomically while holding the iPad together with the other players. These radial sliders are responsible for tweaking the recorded audio samples with individual effects, which will be detailed further down. The big black oval in the middle of the interface serves as a container for the audio-visualiser, which will be further broken down in the following section.

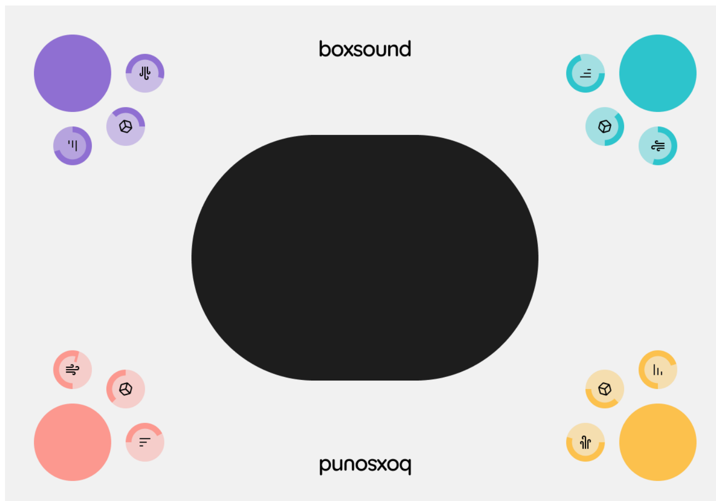

Fig. 13. Final version of the High-Fidelity Graphical User Interface made in Figma

7.2.2 Audio Sampler and Looper Architecture. Similarly to the previous iteration, the implementation of this version was also carried out through Unity and Chuck. In ChucK, one of the main building blocks is unit generators (ugens) which can take forms as various audio effects, oscillators, filters, etc.[13] One specific ugen is called LiSa, which stands for Live Sampling, and it can be used to build loopers with live input or granular synthesis engines[14]. There are four separate instances of LiSa running simultaneously in the prototype, and they can be recorded, and playback sounds concurrently. In this section, we only showcase the implementation of a single instance of the sampler and looper, as they share the same setup and architecture, displayed in Appendix D Listing 3.

Lines 1-3 show the signal chain for a recording button from left to right. First, we connect the analogue to digital converter (adc) to the LiSa ugen, which enables microphone input into the sampler. Next, we connect the output of the sampler to a gain, filter, reverb and delay ugens before the final step; the dac. Next, in lines 4-7, we allocate 4 seconds from memory for the total length of the sampler. Next, we set ramping for the edges of the record buffer to avoid clipping and sharp noises. Next, we have two functions, *recordSound1* (lines 9-20) and *playRecording1* (lines 22-53), both taking events as parameters. Then in the first lines of both functions, the events are called, creating an event callback loop. This is essential for the record and play functions, as they are the main communication between Chuck and Unity. Thus, to start the recording or playback of a loop, when

[13]https://chuck.stanford.edu/doc/program/ugen.html
[14]https://chuck.stanford.edu/doc/program/ugen_full.html#LiSa

one user touches the record button, a global event is sent from Unity to Chuck, which then gets passed as the parameter of the recording or playback function, executing the code in these functions.

It is important to note that the four different LiSa instances' recording and playback functions all run on different threads, enabling simultaneous strongly-timed real-time performance. Moreover, when users want to rerecord a loop, this architecture robustly enables them.

7.2.3 Effects. In this final version, we also implemented the accelerometer-based embodied sound modulation, as already detailed in the previous iteration. However, we tweaked the mechanics based on the children's feedback and made the sound changes more swift and responsive to movements. This was achieved by lowering the filtering threshold of the accelerometer input and applying less smoothing to the data. Furthermore, we adjusted various effect parameters manually for a more playful result, such as introducing an echo effect with different feedback times for the individual recordings.

Apart from the global, embodied audio effects, we implemented three other effects attached to each of the four recording buttons, as seen in Figure 13. These played a more individual role, so they could provide handles for children to tailor their recording and gain more ownership over their sonic expression. Additionally, these effects also served a utilitarian purpose; if the recorded sound would get too loud, noisy or unpleasant for the children, they could use these controls to combat the issue. We implemented three effects: playback rate controlling pitch, speed and direction, volume and a low-pass filter. We implemented the radial sliders based on Unity's built-in UI Slider component. We connected it to Chuck via syncing global Chuck variables and C# variables, as seen in Appendix D Listing 4.

7.2.4 Audio-visualiser. Finally, we created an audio-visualiser in Unity to provide comprehensive visual feedback of the currently playing sonic field. We chose to represent the audio waveform in real-time in a circular shape. We used a waveform analysis implementation through a Fast-Fourier Transform and Hanning window of the real-time audio input coming from the microphone. Then we instantiated sphere prefabs at every sample of of the waveform, which we set at 1024. These would update real-time, and represent a responsive visual audiowaveform. The colours of the visualiser represented the four primary colours of the interface. We It is important to note that we strove to keep the visualiser minimalistic and not overstimulating, as too much visual and sonic stimulation might overwhelm some children with ASC. The designed visualiser can be seen in Figure 14.

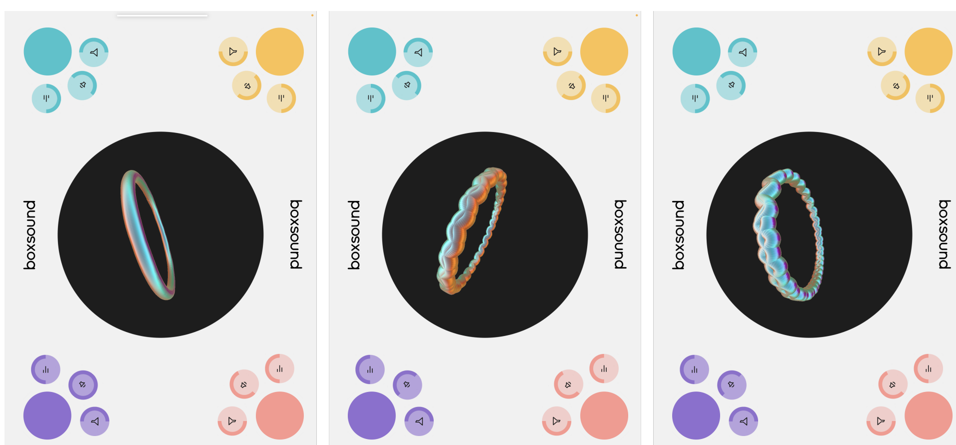

Fig. 14. The audio-visualiser component in its default state (left) and in different stages reacting to various sounds (middle, right)

7.3 Process

We conducted a case study of our prototype in collaboration with four students with ASC (S1, S2, S3, S4) and two SEN teachers (T1, T2) at Skolen Sputnik with two researchers present (R1, R2). Before diving into the workshop, we provided a concise overview of the process we had undertaken thus far. We highlighted how the previous workshop's components had paved the way for the subsequent stages of the prototype's collaborative creation. Initially, we had anticipated a workshop with six students and two teachers. However, due to a leave of absence, only four students were present—a mix of three boys and one girl. Considering this, we decided to commence the session with all four students, allowing them to explore the prototype simultaneously. Gathering around a round table, we introduced the prototype's functionalities in a brief introduction. We aimed to create an inclusive experience where every student felt engaged and empowered. Before we explained the prototype in detail and ensured the children understood the basic operations, we explained today's narrative scenario. This was the idea of recording a time capsule of today's music and sharing it in 2098 to allow the previously introduced role-playing scientists in PDW 1 to understand how one created music today and help them harness the power of musical intuition and creativity.

7.3.1 Getting to Know the Functionalities of the Prototype. S3 took the initiative and recorded a voiceover using a comic character's voice, sparking immediate interest among the other students. Soon, everyone joined in, primarily focusing on recording spoken sounds. Although we hadn't anticipated this particular direction, we decided to let it unfold naturally, curious to see how it would evolve. As the workshop progressed, three students continued to contribute voice recordings, exploring various internet memes, YouTube characters, and other unconventional sounds. However, S4, one of the students, didn't connect with this approach. After a little while, she expressed her discomfort and politely requested to be excused from the workshop. We acknowledged her feelings and respected her decision, realising that this situation challenged our goal of creating an inclusive experience.

We respected S4's decision and assured her that it was perfectly fine to step away if she didn't feel comfortable participating. One of the SEN teachers accompanied her outside the workshop area to ensure she had a supportive environment. As the three remaining students continued, we consciously tried to pivot the focus away from spoken vocal sounds and explore other forms of audio expression. One of the researchers suggested the use of taps on the table and surrounding objects could create unique sounds when recorded, encouraging the students to experiment and think outside the box. To foster collaboration, we suggested that they take turns, allowing each student to contribute their ideas and sounds in a structured manner. This ensured that everyone had a chance to be heard and valued within the group.

Gathered around the table, we had yet to harness the prototype's motion to modify the sounds. Consequently, we assisted the children in redirecting their efforts towards capturing a more melodic array of sounds. Once satisfied, we rose from the table, and one of the researchers joined the trio of students who stood around the iPad, collectively grasping it. The close proximity posed a challenge for a few of the students. We started a new sound recording and tried to include the continuous movement of the device to add a new set of effects to the soundscape. S2 settled back down, appearing somewhat fatigued from the endeavour; one of the researchers stepped in and assumed his place among the group of four. At this point, the sounds created became more melodic and creative. S1 commented on the capture of a whistle by R1, saying, *"It sounds like Robin Hood. Robin in the Hood!"* He followed up with a comment on the next sound recording by S2, where he made bubbly sounds; *"It sounds kind of banging, my man. It sounds like a jellyfish walking!"* At last, we discovered a mutually shared conceptual space that fostered inclusivity and generated a diverse range of enjoyable sounds for everyone to appreciate. With that achievement, we took a well-deserved ten-minute break.

7.3.2 Reflections During the Break with SEN Teachers. During the break, we discussed with the SEN teachers about S4's departure, contemplating how we could reassess and adapt our approach. It became evident that turn-taking held great significance, prompting one of the teachers, T2, to express, *"That is where the difficulty lies. The concept of 'you and me,' the dialogue, and the interaction in between."* Understanding how others might perceive our actions was a challenging concept for the children in the class. T1 further elaborated on a workshop incident where he attempted to explain to S1 the importance of remaining silent to allow someone else to capture the desired recording. However, S1 struggled to grasp that his actions could disrupt the other person's recording process. T1 also observed that the act of recording seemed to provide an opportunity for some of the children to express inappropriate remarks. He described it as a delicate situation, stating, *"It's like they have this sort of chalice or something, where they dream about saying outrageous things. They just grab the microphone and blurt out things like, 'Let's try to capture all the STDS in one hour on YouTube. You're welcome, heh!'"* The teachers acknowledged this challenge, explaining that it is a recurring issue they encounter throughout the school day. Some of the children tend to dwell in their own mixed-up universes, disconnected from the experiences of others.

Despite the unexpected turn of events, T2 provided reassurance by acknowledging, "Well, it's clear that they are enjoying themselves." We agreed on the goal of collectively trying to withhold their enthusiasm towards a more musical direction after the break and making a more elaborate sound recording to be used as the narrative of the previously mentioned time capsule sound capture. Before proceeding, we reviewed the case study evaluation questionnaire, which the teachers suggested to go through it collectively, as some students had limited reading skills. They hypothesised that this approach would benefit students with reading difficulties and help maintain a steady pace throughout the questionnaire. It was suggested that one of the researchers lead the walkthrough of the questions, emphasising the numerical scoring from one to five while not getting overly absorbed in the text-heavy descriptions. This way, we would address one question at a time, avoiding potentially being overwhelmed by the range of questions and increasing the chances of success.

7.3.3 Recording of Time Capsule Collaborative Soundscape. After the students returned from their break, we proceeded with the remaining two tasks of the workshop. The first task involved creating a purposeful piece of sound, where we encouraged the students to put their creativity into crafting a deliberate musical composition. Once the tune was composed, we planned to record it while utilising the movement of the device to alter the music collectively. As we once again described the narrative aspect of the idea of recording a soundscape to be sent to the future in a time capsule, S3 raised a question about our idea of transmitting a soundscape to the future; *How do we know that our future descendants will be able to comprehend sound?* An interesting thought led to further reflection within the group regarding how we should create the sound recording. Following the recording session, we gathered to review the questionnaire as planned during the break with the teachers.

We started the collaborative music-making session seated once again and ensured that the researchers and teachers actively contributed to conveying a form of rhythmic scaffolding for the students. We took turns guiding the children in creating sounds, ensuring each contribution was directed towards a cohesive and engaging experience, deliberately avoiding repetition of previous comedic skits. This made it a much more orderly process, and the result was surprisingly good. They found small Lego pieces that clicked together, creating a rhythmic pattern. They experimented with clacking metal objects, producing metallic tones that added depth to the soundscape. Some even incorporated their non-verbal vocals, using their voices as musical instruments, generating a melodic and harmonic dimension to the composition. Throughout the process, the children had the opportunity to assess and modify their creations using various effects. They adjusted the recorded sounds' pitch, tempo, and volume, experimenting with different combinations to achieve the desired mood and impact. It seemed as if the continuous interaction with the effects allowed them to refine their creations and explore the boundaries of their imagination, as seen in Figure.

Fig. 15. Focused faces while recording the time capsule at PDW3

Once the soundscape had become something we all found pleasant, we stood up, holding the recording device together. Without vocal communication, we instinctively moved in different directions, synchronising our movements to the evolving soundscape. As we navigated the space, S1 expressed his fascination, remarking, *"It sounds like we are walking into another dimension!"* It was as if the created soundscape had transformed the ordinary classroom into a mystical realm where the power of sound transcended physical boundaries. While S3 pondered, *"This is the sound of how people with dementia feel. (...) Because their mind is warping."* His profound observation highlighted the emotional impact of the soundscape, invoking empathy and understanding for those experiencing cognitive challenges. With a newfound appreciation for the expressive capabilities of sound, the recording session concluded, leaving everyone with a sense of accomplishment. Not only had the children explored their creativity, but they also experienced sound's ability to evoke emotions and convey narratives.

7.3.4 uMARS Scores. After the recording session, we gathered as a group to review the questionnaire. Each student was given a copy to reflect on their experience and provide feedback. R2 and T1 led the walk-through together of the questionnaire, ensuring that everyone could express their thoughts and suggestions for improvement and gather feedback on the prototype's engagement, functionality, aesthetics, and subjective quality. To achieve this, we utilised a modified version of uMARS, focusing the questions on relevance to our application and adapting certain statements to suit our context better. Reviewing the questionnaire together proved valuable, as some students found it challenging to complete without assistance. S2 had no trouble reading and filling it out independently, proceeding at their own pace. For the other two students, S1 and S3, we meticulously examined each questionnaire question in collaboration with T1. This process was crucial, as it helped them comprehend the concepts and ensured that they followed along at a steady and unhurried pace, allowing ample time to reach their decisions without feeling stuck. See the individually calculated scores and average scores of the uMARS subscales in Tabular 5 and the complete questionnaire in Appendix A. The App Quality is measured on a scale of one to five, with a higher score indicating better quality. It is determined by averaging the scores of four subscales: Engagement, Functionality, Aesthetics, and Subjective Quality.

ID	Engagement	Functionality	Aesthetics	Subjective Quality	App Quality
S1	3.0	4.0	3.3	2.7	3.3
S2	3.5	3.3	4.7	2.0	3.5
S3	2.3	3.7	3.0	2.3	2.8
T1	3.8	4.0	3.3	3.3	3.6
T2	4.3	4.3	4.0	4.0	4.2
Average Score	3.4	3.9	3.7	2.8	3.4

Table 5. Scores from the uMARS questionnaire based on the case study of the prototype

As the workshop drew close, we expressed our gratitude to the remaining students for their valuable contributions and participation. We thanked them for their patience and continuous help in developing the prototype, emphasising that their voices mattered in shaping the final product. With the insights gained from this workshop, we would now analyse the recorded data, observations, and feedback gathered from the students and teachers. This analysis would enable us to refine our project conclusions and provide suggestions for future research in utilising CADMIs to foster social understanding and inclusivity while expanding the creative possibilities for accessible target groups. However, before embarking on this analysis, we conducted a post-interview with the two SEN teachers to delve deeper into their perspectives on the prototype's effectiveness in a day-to-day scenario used during breaks between classes at Skolen Sputnik.

7.3.5 Post-Interview Effectiveness Evaluation. The objective of conducting a follow-up interview with the two teachers of the class aimed to gain further insights into their viewpoints regarding using the prototype as an app during school breaks. Our focus encompassed various aspects, such as exploring the potential improvements in social skills for children with ASC, fostering awareness of others, enhancing collaboration abilities, and facilitating effective communication. Initially, they discovered the app's features to be captivating. After overcoming the initial challenges of using it for the first time, T1 remarked that *"It could be quite fun for us, like a conversation starter tool."* As to which to T2 added that *"The interaction and the communication are what they (ref. the children with ASC) are struggling with, it is difficult for them."* This led the conversation to the possibility of including a music teacher or therapist in a session that would orchestrate the children in their pursuit of sounds and help them understand the different elements of building a musical score. T2 added that as of now, there probably was a lack of intrinsic motivation to create music in general for the students that had participated in the workshop, noting that; *"I think if you had another group that was interested in creating music. And could think that "Oh, it would be nice to make music today' Then I think it could do wonders. Because you will have another form of goal and intention. (...) That is what we see with other activities around the school. That once there is a group with a shared goal, they can really do well together."* Hence, T2 proposed two possibilities: either the students should have a clear motivation to create music in order to appreciate the experience fully, or alternatively, there should be a more structured environment with a designated facilitator who ensures inclusivity, turn-taking and a deeper musical comprehension throughout the process.

In addition to motivation, having a purpose or goal within the process is also important. T1 proposed the idea of recreating a favourite song together as a goal, saying, *"It could be fun if there's a song that you like, and you try to recreate the song together so that there is a goal."* This suggestion prompted T2 to propose the idea of distributing roles or creating sound stations; *"Maybe you could also categorise the sounds. So that, one has to make a sound with* *their hands. While another has to whistle etc. (...) So that when it comes to their turn, they don't have to use all their energy to like, 'Oh my god, what am I supposed to do'."* Suggesting incorporating a larger conceptual framework around the app as a tool for intervention and using collaborative music-making as the medium to practice already established protocols within music and movement therapy, empathising the importance of guided interaction and communication for children who struggle in these areas.

8 DISCUSSION

During the participatory design (PD) process of boxsound, we followed an iterative research, design, development, and evaluation approach. This approach allowed us to gain valuable insights at various levels and helped us understand the practical implications of co-designing with children with Autism Spectrum Condition (ASC). Through our participatory action research, we had the opportunity to actively engage with children with ASC and learn firsthand about their needs, preferences and ideas. We thoroughly examined therapeutic practices and various theories that promote collaboration through technology. Additionally, we studied previous research on collaborative accessible digital musical interfaces (CADMI) to establish a foundation for our project. The initial stage of the User Requirements Workshops (URW) offered valuable insights into potential engaging approaches for including children with ASC in the design process. We discovered effective strategies and techniques to ensure their active participation and engagement. Building on the insights gathered from the URW, we moved forward with the participatory design workshops (PDW). These workshops were designed to include a solid framework for effectively involving children with ASC in the PD process. The framework incorporated the lessons learned from the URW. It provided a structured approach to conceptualising a technological prototype designed to help children with ASC's social abilities, awareness of others, collaboration, and communication.

In this section, we will explore three levels of abstraction derived from our key learnings in involving children with ASC in a PD process to create a CADMI:

(1) **Usability Considerations**: Review of the prototype's performance in terms of design decisions and sharing our thoughts and ideas on its technical aspects. We will also provide suggestions for design and functionality enhancements based on the uMARS scores, interviews with SEN teachers and our observations and experiences.

(2) **Collaboration and movement for children with ASC**: Present perspectives on how the prototype's conceptual framework revolving around shareable interfaces and movement synchrony can be adapted and modified to suit its intended context better. This will involve considering potential adjustments that can be made to improve its effectiveness.

(3) **Key Insights from Conducting Participatory Action Research Methodology**: Provide an overview of the entire participatory action research design process, which spanned over six months and involved two distinct SEN schools in Copenhagen and Silicon Valley. By encompassing these diverse settings, we gained valuable insights and experiences, contributing to our comprehensive understanding of the project.

8.1 Usability Considerations

In this deliberation, we will evaluate the prototype's performance from a technical standpoint and share our thoughts and ideas regarding its usability aspects and overall user experience. Additionally, we will provide suggestions for design and functionality enhancements based on the uMARS scores, interviews with SEN teachers and our own experiences.

Overall, the prototype demonstrated commendable functionality and showed promise in assisting SEN students. Scores from the uMARS questionnaire indicate the students' and teachers' experience of interacting with the prototype, arguably engaging and offering them satisfactory functionalities. Upon observation, the user interface appeared intuitive, further supported by the positive feedback received in the aesthetics subscale of the uMARS. We were particularly interested in assessing the stability and response time of the prototype, and we found them to be generally satisfactory, ensuring a smooth user experience and minimising frustration. There was only one instance during the session where the prototype's app abruptly shut down, but aside from that, no noticeable technical issues were encountered throughout the case study.

Nevertheless, we did identify a few areas where the prototype could be enhanced. Firstly, there is room for improvement in the accuracy of the recording button. Although it could record sound snippets successfully, it occasionally faced challenges in accurately capturing the intended length, as indicated by the UI on the button. This inconsistency led to confusion regarding the recorded sound's outcome, as it would sometimes include audible portions that occurred before the button was pressed or result in a significantly shorter snippet than indicated.

Furthermore, the effects of the prototype could be further refined to provide a less error-prone experience. In the initial stages of the case study, several students only utilised audio layers of vocal speech. However, when combined with the effects set to maximum, the resulting audible output was not very pleasing to listen to. This caused visible frustration among some students and teachers. Additionally, we observed that fine-tuning the effects was not as straightforward as anticipated. The relatively small buttons for adjusting the effects did not offer an intuitive way to interact and make precise adjustments. It was noticed that students often resorted to either set the effect to the maximum or minimum, treating it more like a button than a slider. We also observed several instances where participants attempted to use the effects as buttons, especially one of the teachers. It might be worth considering an interesting addition to the slider or button, where a tap could turn the effect on or off, providing a convenient alternative to adjusting it.

Another crucial consideration is the inclusion of a play and pause or global mute option. Currently, exiting the app every time a new soundscape is desired can be quite cumbersome. Additionally, sliding down all the audio sliders on each of the four recording corners can be made more convenient with a global mute button. Through our interviews with SEN teachers, we discovered that creating specific scenarios for each sound corner could greatly encourage children to capture particular types of sounds. Incorporating features that guide users towards a specific rhythmic direction could be particularly beneficial for individuals with limited musical inclination. Facilitating assistance and guidance in the creation of a musical score would enhance engagement in the process, particularly in situations where there isn't a designated person available to orchestrate the experience. This additional system-based support could enable users to navigate their creation of the score more effectively and foster a deeper level of involvement and understanding in the overall collaborative experience.

It would be beneficial to incorporate an export and save function in the prototype would be helpful. This feature would allow users to export their sound creations as .wav files and potentially save their progress for future sessions. Similarly, an import mode could be implemented, enabling users to import a backing track as a starting point, providing a baseline for the musicking process. The incorporation of these features would enhance the longevity of the experience. While users did not explicitly express a strong desire for extended interaction with the current state of the prototype, these additions would offer the flexibility and functionality necessary to sustain engagement over time.

8.2 Collaboration and Movement for Children with ASC

The main conceptual goal of this project was to facilitate collaboration and cooperative play between children with ASC through making music together with a shareable interface and using movement synchrony to change musical parameters. We used the iPad as the target device due to its characteristics suitable for co-located collaboration. It allows simultaneous multiplayer action due to its size and multi-touch functionalities, as suggested by Boyd et al. [10]. We observed that our interface design utilised the iPad's four corners as separate play areas and distinguishing roles with individual colours–which have successfully facilitated simultaneous co-located collaboration. Children understood this concept from the beginning and used the prototype accordingly. This metaphor also helped differentiate between recorded tracks when only two children played together instead of four.

However, a more explicit collaboration metaphor or concept could have engaged and involved the students even more for an extended time. According to Yuill's taxonomy [83], we designed an exploratory collaboration metaphor instead of a guided one. Based on previous works with more verbally-expressive children benefiting from exploratory, collaborative interactions [55] [35], we hypothesised that a collaborative musical experience could benefit such an exploratory approach. However, based on our observations and the interview with the two SEN teachers, this specific group of children might have found a guided collaboration metaphor more engaging in the long run. As one of the teachers pointed out, this group did not share an intrinsic motivation to create music together. T2 suggested that the prototype–with its current exploratory collaboration–could entertain four musically adept children for a more extended period of time, who already share the goal of creating a musical composition. Thus, we deduce that designing guided collaboration from a musical perspective can be more suitable for children without intrinsic motivation to create music together.

The lack of a guided collaboration metaphor can be further extended to the movement aspect of the prototype. During the case study evaluation, we observed that children did not have a passionate urge to tweak sonic parameters with their body movements, even though their suggested changes and improvements were implemented from PDW2's phone prototype to PDW3's iPad prototype. The teachers identified that this might be due to the lack of specific roles or tasks within the movement-based collaboration aspect of the prototype. As one of them put it, the embodied musical effects achieve the same result whether one user moves the iPad or all four of them. Thus, incorporating a more constrained collaboration model here could also be more appropriate for this specific group of children. Alternatively, keeping the exploratory approach could benefit from adding a music or movement therapist's guidance and expertise.

Finally, using the iPad as a shareable interface posed some challenges. The students who participated in the PD process are not in close friendships; thus, sharing one device in close proximity to each other might have caused discomfort in some students. The teachers confirmed this and even suggested that touching the same physical object simultaneously might be too intimidating for a few children in this group.

8.3 Key Insights from Conducting Participatory Action Research Methodology

Engaging in participatory research is by no means a straightforward one. When users are involved in the design process, it often leads to innovative and unconventional approaches to developing technological prototypes. Embracing these fresh perspectives requires adaptability and a willingness to compromise throughout the entire process. Holone et al. [33] shed light on some of the inevitable compromises that arise when translating the research framework into real-life projects; such the challenges encountered in embracing fresh perspectives is the necessity to allocate time to establish shared vocabularies for discussing the designed artefacts. Building trust among the involved parties becomes crucial, including considerations of language and communication. And the fact that children with ASC may not be accustomed to actively participating and taking on decision-making roles as they are more familiar with others making decisions on their behalf.

In our encounters, our envisioned workshop sessions rarely unfolded as we had anticipated. Understanding the intricacies of neurodiversity presents a formidable challenge. It is not a simple task to put oneself in the mindset of individuals with diverse neurological profiles, as noted by previous researchers [23]. However, recognising the importance of learning from firsthand experiences is crucial. The user research workshops (URW) served as a pivotal foundation and were invaluable in preparing us to navigate the complexities of engaging with children with ASC during the design process. We found using introduction games vital to establish a trustworthy relationship between ourselves and the neurodiverse children. This approach was slimmed down and adopted during PDW1 to be more effective, as we found it took too much of our allocated time during the URW. This helped us to incorporate aspects of a Handlungspielraum [51] and provided us with insights into the diverse perspectives, needs, and preferences of the individuals, equipping us with the necessary knowledge and skills to conduct the participatory design workshops (PDW) effectively.

Throughout the URW sessions, we also had the privilege of collaborating with Lloyd May[15] and Matt Robidoux[16], whose expertise in facilitating auditory experiences for neurodiverse individuals proved invaluable. They enriched our understanding and helped shape the conceptual research space we were working in and establish specific techniques and strategies to engage children with ASC in the design process effectively. These included creating a structured and predictable environment, using visual supports and aids, employing clear and concise communication, and incorporating their interests and motivations into the design activities, as also suggested by Makhaeva et al. [51]. The importance of structure and predictability for children with ASC throughout the workshops was also further emphasised during our meeting with the teachers and staff at Skolen Sputnik, which led us to create agendas for the PDW workshops as shown in Appendix A and E.

Furthermore, we encountered situations where some students at Stanbridge Academy did not always fully appreciate our presence during the URW. After discussing this with Lloyd and Matt, we realised that it may have been because we were taking time away from a music class that certain students particularly enjoyed. We also observed that focus and engagement levels were not consistently optimal, which Matt pointed out might be attributed to our workshops taking place at the end of the day when the children's energy levels were depleted. These insights proved valuable as we embarked on planning sessions with Skolen Sputnik. In light of these learnings, we suggested that children voluntarily sign up for the workshops, and we decided to schedule the sessions in the morning to ensure better participation and attentiveness.

Throughout the process, we employed a variety of methods to collect feedback. Based on suggestions by Makhaeva et al. [51] and Ward et al. [78], we recognised that there is no one-size-fits-all approach to gathering feedback from children with ASC. Consequently, we continuously refined our methods for engaging the children in the design thinking process. During the initial URW, we approached the session with an open mindset, allowing Matt to take the lead in the classroom and pose questions for discussion. However, we discovered that open-ended questions did not yield substantial depth in the responses. The neurodiverse children tended to express themselves concisely and lacked the inclination to reflect upon shared experiences. This observation prompted us to reassess our approach to ensure we could capture more nuanced insights.

A key aspect in bringing children with ASC within the process was contextualising it through a narrative. This process started slightly during the URW and was more thoroughly implemented in the PDW from the get-go. Teachers from both Stanbridge Academy and Skolen Sputnik emphasised that if there is not an explainable reason for doing the workshops, the children might find it difficult to relate to or participate meaningfully. Related research within the fictional inquiry, such as the IDEAS framework by Benton et al. [6], suggests using fictional roles, such as; user, tester, informant and design partner. We combined this in a narrative roleplaying scenario inspired by Moraveeji et al. [56], adding a layer of playfulness and a shared narrative storyline to contextualise the workshops and learn if this helped engage the children with ASC to access their creative minds through play and imagination.

We commenced the PDW sessions by strongly emphasising establishing a narrative. To enhance the experience, we created visually appealing aids in the form of roleplaying cards and a recorded video featuring a futuristic

[15] https://journeys.dartmouth.edu/lloydmay/
[16] https://www.mattrobidoux.com/

scientist who called upon the participants to embark on a mission to preserve collaborative music-making for the future. This approach resonated with the participants to some extent. However, as the workshop neared its conclusion, the combination of receiving a roleplaying character and engaging in a conceptual design thinking activity overwhelmed the children cognitively. The SEN teachers explained that this level of abstraction caused confusion among the students regarding their roles when brainstorming new ideas. Incorporating the participatory action research approach outlined by Ward et al. [78], we decided to refine our utilisation of narrative and simplify the roleplaying element to alleviate cognitive demands for children with ASC. As a result, our workshops maintained contextualisation within the presented narrative but less emphasised individual roleplaying responsibilities.

9 LIMITATIONS

This study has several limitations that should be considered. Firstly, the sample size was relatively small, with only six participants from each collaborating institution and three ASC children in the case study. This limited sample size may restrict the generalisability of the findings to a larger population of children with ASC. Another limitation is the potential bias introduced during the participatory design process. While the process aimed to accommodate the unique strengths of individuals with ASC, it is important to acknowledge that participants' preferences, perspectives, and the researcher's interpretations and decisions during the design workshops, may have influenced the final prototype.

The evaluation of the 'boxsound' prototype relied on subjective assessments, such as engagement, functionality, aesthetics, and subjective quality. Subjective evaluations can be influenced by individual biases, and there might be a need for more objective measures to provide a comprehensive assessment of the prototype's effectiveness. Additionally, the study's findings and the 'boxsound' prototype may have limited generalisability to a broader range of ASC populations. Autism spectrum condition encompasses a diverse range of individuals with varying abilities, interests, and needs. The specific characteristics and requirements of the participants involved in this study may not fully represent the entire spectrum of ASC.

Furthermore, the study lacked a long-term evaluation to assess the prototype's sustained impact on collaboration, cooperative work, and communication skill development among children with ASC. Long-term evaluations are essential to understanding the prototype's efficacy over time. The study mainly incorporated insights from SEN teachers, while other stakeholders, such as parents, caregivers, and therapists, were not included. Including a broader range of perspectives could provide a more comprehensive understanding of the prototype's potential benefits and limitations in real-world settings.

Lastly, ethical considerations related to working with children with ASC should be acknowledged. Safeguarding participant confidentiality, obtaining informed consent, and ensuring the well-being and comfort of the participants were critical aspects that needed to be carefully addressed and managed. While these limitations provide important insights, they should be seen as opportunities for further research and improvement rather than detracting from the value and significance of the study's contributions.

10 CONCLUSION

This research project addresses the challenges faced by children with autism spectrum condition (ASC). It focuses on developing a collaborative accessible digital musical interface (CADMI) through a participatory design (PD) process. By involving children with ASC in the design process, we aim to promote collaboration, cooperative work, and the development of communication skills among them through a technological musical co-creation prototype.

A participatory action research approach was employed throughout the project, incorporating fictional inquiry narratives and non-digital activities. This approach is continuously adapted to accommodate and leverage the unique strengths of individuals with ASC. The PD workshops led to creation of a prototype named 'boxsound', which consistently prioritised the user's perspective, striving to bridge different viewpoints to develop an applicable technological solution that facilitates the practice of various social skills. Our research offers insights into possible future digital and therapeutic practices based on music and movement aimed at assisting children with ASC in developing non-verbal communication skills, awareness of others, and collaborative understanding.

The primary contributions of this research are as follows: (1) the collaborative creation of an interdisciplinary CADMI prototype through participatory action research; (2) the introduction of interaction design paradigms grounded in collaborative play methods through shareable interfaces; and (3) insights from SEN teachers and children with ASC regarding the effectiveness of the prototype in a special needs education school setting.

In summary, this thesis provides valuable insights into technology co-creation for children with ASC, focusing on collaboration, communication, and social development. By integrating theoretical foundations, participatory design approaches, and interdisciplinary perspectives, this research contributes to the expanding knowledge base in the fields of PD and CADMI, intending to enhance the lives of children with ASC and inspire future research endeavours.

BIBLIOGRAPHY

[1] 2023. https://theraplay.org/

[2] Juliette Alvin. 1991. *Music therapy for the autistic child*. Oxford University Press.

[3] Felicity Baker, Tony Wigram, David Stott, and Katrina McFerran. 2008. Therapeutic songwriting in music therapy: Part I: Who are the therapists, who are the clients, and why is songwriting used? *Nordic Journal of Music Therapy* 17, 2 (2008), 105–123.

[4] Alberto Battocchi, Fabio Pianesi, Daniel Tomasini, Massimo Zancanaro, Gianluca Esposito, Paola Venuti, A Ben Sasson, Eynat Gal, and Patrice L Weiss. 2009. Collaborative Puzzle Game: a tabletop interactive game for fostering collaboration in children with Autism Spectrum Disorders (ASD). In *Proceedings of the ACM international conference on interactive tabletops and surfaces*. 197–204.

[5] Joey Benedek and Trish Miner. 2002. Measuring Desirability: New methods for evaluating desirability in a usability lab setting. *Proceedings of Usability Professionals Association* 2003, 8-12 (2002), 57.

[6] Laura Benton, Hilary Johnson, Emma Ashwin, Mark Brosnan, and Beate Grawemeyer. 2012. Developing IDEAS: Supporting Children with Autism within a Participatory Design Team. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Austin, Texas, USA) *(CHI '12)*. Association for Computing Machinery, New York, NY, USA, 2599–2608. https://doi.org/10.1145/2207676.2208650

[7] Susanne Bødker and Morten Kyng. 2018. Participatory design that matters—Facing the big issues. *ACM Transactions on Computer-Human Interaction (TOCHI)* 25, 1 (2018), 1–31.

[8] Marianna Boso, Enzo Emanuele, Vera Minazzi, Marta Abbamonte, and Pierluigi Politi. 2007. Effect of long-term interactive music therapy on behavior profile and musical skills in young adults with severe autism. *The journal of alternative and complementary medicine* 13, 7 (2007), 709–712.

[9] Adam Boulanger. 2006. *Autism, new music technologies and cognition*. Ph. D. Dissertation. Massachusetts Institute of Technology.

[10] Louanne E Boyd, Kathryn E Ringland, Oliver L Haimson, Helen Fernandez, Maria Bistarkey, and Gillian R Hayes. 2015. Evaluating a collaborative iPad game's impact on social relationships for children with autism spectrum disorder. *ACM Transactions on Accessible Computing (TACCESS)* 7, 1 (2015), 1–18.

[11] Janina Brede, Anna Remington, Lorcan Kenny, Katy Warren, and Elizabeth Pellicano. 2017. Excluded from school: Autistic students' experiences of school exclusion and subsequent re-integration into school. *Autism & Developmental Language Impairments* 2 (2017), 2396941517737511.

[12] John Brooke et al. 1996. SUS: A quick and dirty usability scale. *Usability evaluation in industry* 189, 194 (1996), 4–7.

[13] M Catherine Cappadocia and Jonathan A Weiss. 2011. Review of social skills training groups for youth with Asperger syndrome and high functioning autism. *Research in Autism Spectrum Disorders* 5, 1 (2011), 70–78.

[14] Anne Marie Chalfant, Ron Rapee, and Louisa Carroll. 2007. Treating anxiety disorders in children with high functioning autism spectrum disorders: A controlled trial. *Journal of autism and developmental disorders* 37 (2007), 1842–1857.

[15] Wei Chen, Jing Zhang, and Jun Ding. 2008. Mirror system based therapy for autism spectrum disorders. *Frontiers of medicine in China* 2 (2008), 344–347.

[16] Franceli L Cibrian, Oscar Peña, Deysi Ortega, and Monica Tentori. 2017. BendableSound: An elastic multisensory surface using touch-based interactions to assist children with severe autism during music therapy. *International Journal of Human-Computer Studies* 107 (2017), 22–37.

[17] John O Cooper, Timothy E Heron, William L Heward, et al. 2007. Applied behavior analysis. (2007).

[18] Hanne De Jaegher. 2013. Embodiment and sense-making in autism. *Frontiers in integrative neuroscience* 7 (2013), 15.

[19] Christian Dindler and Ole Sejer Iversen. 2007. Fictional inquiry—design collaboration in a shared narrative space. *CoDesign* 3, 4 (2007), 213–234.

[20] Allison Druin. 1999. Cooperative Inquiry: Developing New Technologies for Children with Children. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Pittsburgh, Pennsylvania, USA) *(CHI '99)*. Association for Computing Machinery, New York, NY, USA, 592–599. https://doi.org/10.1145/302979.303166

[21] Andreas Förster, Christina Komesker, and Norbert Schnell. 2020. Snoesky and sonicdive-design and evaluation of two accessible digital musical instruments for a Sen school. In *Proceedings of the International Conference on New Interfaces for Musical Expression*. 83–88.

[22] Marcus Foth and Jeff Axup. 2006. Participatory design and action research: Identical twins or synergetic pair?. In *Expanding Boundaries in Design: Proceedings Ninth Participatory Design Conference 2006 (Vol 2)*. Computer Professionals for Social Responsibility, 93–96.

[23] Christopher Frauenberger, Judith Good, and Wendy Keay-Bright. 2011. Designing technology for children with special needs: bridging perspectives through participatory design. *CoDesign* 7, 1 (2011), 1–28.

[24] Christopher Frauenberger, Kay Kender, Laura Scheepmaker, Katharina Werner, and Katta Spiel. 2020. Desiging Social Play Things. In *Proceedings of the 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society* (Tallinn, Estonia) *(NordiCHI '20)*. Association for Computing Machinery, New York, NY, USA, Article 24, 12 pages. https://doi.org/10.1145/3419249.3420121

[25] Christopher Frauenberger, Julia Makhaeva, and Katta Spiel. 2017. Blending Methods: Developing Participatory Design Sessions for Autistic Children. In *Proceedings of the 2017 Conference on Interaction Design and Children* (Stanford, California, USA) *(IDC '17)*. Association for Computing Machinery, New York, NY, USA, 39–49. https://doi.org/10.1145/3078072.3079727

[26] Emma Frid. 2019. Accessible digital musical instruments—a review of musical interfaces in inclusive music practice. *Multimodal Technologies and Interaction* 3, 3 (2019), 57.

[27] Emma Frid, Claudio Panariello, and Claudia Núñez-Pacheco. 2022. Customizing and Evaluating Accessible Multisensory Music Experiences with Pre-Verbal Children—A Case Study on the Perception of Musical Haptics Using Participatory Design with Proxies. *Multimodal Technologies and Interaction* 6, 7 (2022), 55.

[28] Eynat Gal, Nirit Bauminger, Dina Goren-Bar, Fabio Pianesi, Oliviero Stock, Massimo Zancanaro, and Patrice L Weiss. 2009. Enhancing social communication of children with high-functioning autism through a co-located interface. *Ai & Society* 24 (2009), 75–84.

[29] Gustavo Schulz Gattino, Rudimar dos Santos Riesgo, Dânae Longo, Júlio César Loguercio Leite, and Lavina Schüler Faccini. 2011. Effects of relational music therapy on communication of children with autism: a randomized controlled study. *Nordic Journal of Music Therapy* 20, 2 (2011), 142–154.

[30] Monika Geretsegger, Cochavit Elefant, Karin A Mössler, and Christian Gold. 2014. Music therapy for people with autism spectrum disorder. *Cochrane Database of Systematic Reviews* 6 (2014).

[31] Christian Gold, Tony Wigram, and Cochavit Elefant. 2006. Music therapy for autistic spectrum disorder. *Cochrane database of systematic reviews* 2 (2006).

[32] Steven Gutstein and Rachelle K Sheely. 2002. *Relationship development intervention with children, adolescents and adults: Social and emotional development activities for Asperger syndrome, autism, PDD and NLD.* Jessica Kingsley Publishers.

[33] Harald Holone and Jo Herstad. 2013. Three Tensions in Participatory Design for Inclusion. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris, France) *(CHI '13)*. Association for Computing Machinery, New York, NY, USA, 2903–2906. https://doi.org/10.1145/2470654.2481401

[34] Eva Hornecker, Paul Marshall, and Yvonne Rogers. 2007. From entry to access: how shareability comes about. In *Proceedings of the 2007 conference on Designing pleasurable products and interfaces*. 328–342.

[35] Juan Pablo Hourcade, Stacy R Williams, Ellen A Miller, Kelsey E Huebner, and Lucas J Liang. 2013. Evaluation of tablet apps to encourage social interaction in children with autism spectrum disorders. In *Proceedings of the SIGCHI conference on human factors in computing systems*. 3197–3206.

[36] Balazs Ivanyi, Christian Tsalidis, Scott Naylor, Truls Tjemsland, Ali Adjorlu, Nille Elise Kepp, and Stefania Serafin. 2022. HoloBand: An Augmented Reality Experience to Train Music Perception for the Hard of Hearing. In *Audio Engineering Society Conference: AES 2022 International Audio for Virtual and Augmented Reality Conference*. Audio Engineering Society.

[37] Balazs Andras Ivanyi, Truls Bendik Tjemsland, Christian Vasileios Tsalidis de Zabala, Lilla Julia Toth, Marcus Alexander Dyrholm, Scott James Naylor, Ann Paradiso, Dwayne Lamb, Jarnail Chudge, Ali Adjorlu, et al. 2023. DuoRhythmo: Design and remote user experience evaluation (UXE) of a collaborative accessible digital musical interface (CADMI) for people with ALS (PALS). In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. 1–13.

[38] Daniel Johnston, Hauke Egermann, and Gavin Kearney. 2018. Innovative computer technology in music-based interventions for individuals with autism moving beyond traditional interactive music therapy techniques. *Cogent Psychology* 5, 1 (2018), 1554773.

[39] Sergi Jordà, Martin Kaltenbrunner, Günter Geiger, and Ross Bencina. 2005. The reactable. In *ICMC*. Citeseer.

[40] Rita Jordan. 1993. The nature of the linguistic and communication difficulties of children with autism. *Critical influences on child language acquisition and development* (1993), 229–249.

[41] Leo Kanner et al. 1943. Autistic disturbances of affective contact. *Nervous child* 2, 3 (1943), 217–250.

[42] Ronna S Kaplan and Anita Louise Steele. 2005. An analysis of music therapy program goals and outcomes for clients with diagnoses on the autism spectrum. *Journal of music therapy* 42, 1 (2005), 2–19.

[43] Wendy Keay-Bright and Imogen Howarth. 2012. Is simplicity the key to engagement for children on the autism spectrum? *Personal and ubiquitous computing* 16 (2012), 129–141.

[44] Kay Kender, Christopher Frauenberger, Johanna Pichlbauer, and Katharina Werner. 2020. Children as Designers - Recognising Divergent Creative Modes in Participatory Design. In *Proceedings of the 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society* (Tallinn, Estonia) *(NordiCHI '20)*. Association for Computing Machinery, New York, NY, USA, Article 18, 11 pages. https://doi.org/10.1145/3419249.3420145

[45] Jinah Kim, Tony Wigram, and Christian Gold. 2008. The effects of improvisational music therapy on joint attention behaviors in autistic children: a randomized controlled study. *Journal of autism and developmental disorders* 38 (2008), 1758–1766.

[46] Amy C Laurent and Emily Rubin. 2004. Challenges in emotional regulation in Asperger syndrome and high-functioning autism. *Topics in Language Disorders* 24, 4 (2004), 286–297.

[47] Kelle M Laushey and L Juane Heflin. 2000. Enhancing social skills of kindergarten children with autism through the training of multiple peers as tutors. *Journal of autism and developmental disorders* 30 (2000), 183–193.

[48] Hoo Yong Leng, Noris Mohd Norowi, and Azrul Hazri Jantan. 2017. A User-Defined Gesture Set for Music Interaction in Immersive Virtual Environment. In *Proceedings of the 3rd International Conference on Human-Computer Interaction and User Experience in Indonesia* (Jakarta, Indonesia) *(CHIuXiD '17)*. Association for Computing Machinery, New York, NY, USA, 44–51. https://doi.org/10.1145/3077343.3077348

[49] Joana Lobo, Soichiro Matsuda, Izumi Futamata, Ryoichi Sakuta, and Kenji Suzuki. 2019. CHIMELIGHT: Augmenting Instruments in Interactive Music Therapy for Children with Neurodevelopmental Disorders. In *Proceedings of the 21st International ACM SIGACCESS Conference on Computers and Accessibility* (Pittsburgh, PA, USA) *(ASSETS '19)*. Association for Computing Machinery, New York, NY, USA, 124–135. https://doi.org/10.1145/3308561.3353784

[50] Julie Lounds, Marsha Mailick Seltzer, Jan S Greenberg, and Paul T Shattuck. 2007. Transition and change in adolescents and young adults with autism: Longitudinal effects on maternal well-being. *American Journal on Mental Retardation* 112, 6 (2007), 401–417.

[51] Julia Makhaeva, Christopher Frauenberger, and Katta Spiel. 2016. Creating creative spaces for co-designing with autistic children: the concept of a" Handlungsspielraum". In *Proceedings of the 14th Participatory Design Conference: Full papers-Volume 1*. 51–60.

[52] Robert C Martin. 2000. Design principles and design patterns. *Object Mentor* 1, 34 (2000), 597.

[53] Hanna Mayer-Benarous, Xavier Benarous, François Vonthron, and David Cohen. 2021. Music therapy for children with autistic spectrum disorder and/or other neurodevelopmental disorders: a systematic review. *Frontiers in psychiatry* 12 (2021), 643234.

[54] Anne Steen Møller, Helen Odell-Miller, and Tony Wigram. 2002. Indications in music therapy: Evidence from assessment that can identify the expectations of music therapy as a treatment for autistic spectrum disorder (ASD); meeting the challenge of evidence based practice. *British Journal of Music Therapy* 16, 1 (2002), 11–28.

[55] Joan Mora-Guiard, Ciera Crowell, Narcis Pares, and Pamela Heaton. 2017. Sparking social initiation behaviors in children with Autism through full-body Interaction. *International Journal of Child-Computer Interaction* 11 (2017), 62–71.

[56] Neema Moraveji, Jason Li, Jiarong Ding, Patrick O'Kelley, and Suze Woolf. 2007. Comicboarding: using comics as proxies for participatory design with children. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. 1371–1374.

[57] Phoebe Morris, Edward Hope, Tom Foulsham, and John P Mills. 2021. The effectiveness of mirroring-and rhythm-based interventions for children with autism spectrum disorder: A systematic review. *Review Journal of Autism and Developmental Disorders* (2021), 1–21.

[58] Antonio Narzisi, Colombi Costanza, Balottin Umberto, and Muratori Filippo. 2014. Non-pharmacological treatments in autism spectrum disorders: an overview on early interventions for pre-schoolers. *Current clinical pharmacology* 9, 1 (2014), 17–26.

[59] Antonella Nonnis and Nick Bryan-Kinns. 2019. Mazi: Tangible Technologies as a Channel for Collaborative Play. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300670

[60] World Health Organization. March 29, 2023. Autism Key facts. Retrieved May 21, 2023 from https://www.who.int/news-room/fact-sheets/detail/autism-spectrum-disorders

[61] Danielle Provenzano. 2020. Music Therapy for Communication in Children with Autism Spectrum Disorder. (2020).

[62] Grazia Ragone, Judith Good, and Katherine Howland. 2020. OSMoSIS: Interactive sound generation system for children with autism. In *Proceedings of the 2020 ACM Interaction Design and Children Conference: Extended Abstracts*. 151–156.

[63] Brian Reichow and Erin E Barton. 2014. Evidence-based psychosocial interventions for individuals with autism spectrum disorders. (2014).

[64] Alaine E Reschke-Hernández. 2011. History of music therapy treatment interventions for children with autism. *Journal of Music Therapy* 48, 2 (2011), 169–207.

[65] Toni Robertson and Jesper Simonsen. 2012. Challenges and opportunities in contemporary participatory design. *Design Issues* 28, 3 (2012), 3–9.

[66] Clyde C Robinson, Genan T Anderson, Christin L Porter, Craig H Hart, and Melissa Wouden-Miller. 2003. Sequential transition patterns of preschoolers' social interactions during child-initiated play: Is parallel-aware play a bidirectional bridge to other play states? *Early Childhood Research Quarterly* 18, 1 (2003), 3–21.

[67] Sally J Rogers and Geraldine Dawson. 2020. *Early Start Denver Model for young children with autism: Promoting language, learning, and engagement.* Guilford Publications.

[68] Sara M Scharoun, Nicole J Reinders, Pamela J Bryden, and Paula C Fletcher. 2014. Dance/movement therapy as an intervention for children with autism spectrum disorders. *American Journal of Dance Therapy* 36 (2014), 209–228.

[69] Douglas Schuler and Aki Namioka. 1993. *Participatory design: Principles and practices.* CRC Press.

[70] Greis Francy M Silva-Calpa, Alberto B Raposo, and Francisco R Ortega. 2021. Collaboration support in co-located collaborative systems for users with autism spectrum disorders: A systematic literature review. *International Journal of Human–Computer Interaction* 37, 1 (2021), 15–35.

[71] Greis Francy M Silva-Calpa, Alberto B Raposo, and Maryse Suplino. 2018. CoASD: A tabletop game to support the collaborative work of users with autism spectrum disorder. In *2018 IEEE 6th International Conference on Serious Games and Applications for Health (SeGAH)*. IEEE, 1–8.

[72] Kate Simpson and Deb Keen. 2011. Music interventions for children with autism: narrative review of the literature. *Journal of autism and developmental disorders* 41 (2011), 1507–1514.

[73] Sudha M Srinivasan, Inge-Marie Eigsti, Timothy Gifford, and Anjana N Bhat. 2016. The effects of embodied rhythm and robotic interventions on the spontaneous and responsive verbal communication skills of children with Autism Spectrum Disorder (ASD): A further outcome of a pilot randomized controlled trial. *Research in autism spectrum disorders* 27 (2016), 73–87.

[74] Hideki Takahashi, Kanae Matsushima, and Toshihiro Kato. 2019. The effectiveness of dance/movement therapy interventions for autism spectrum disorder: a systematic review. *American Journal of Dance Therapy* 41 (2019), 55–74.

[75] Lilia Villafuerte, Milena Markova, and Sergi Jorda. 2012. Acquisition of Social Abilities through Musical Tangible User Interface: Children with Autism Spectrum Condition and the Reactable. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems* (Austin, Texas, USA) *(CHI EA '12)*. Association for Computing Machinery, New York, NY, USA, 745–760. https://doi.org/10.1145/2212776.2212847

[76] Santiago Villarreal-Narvaez, Jean Vanderdonckt, Radu-Daniel Vatavu, and Jacob O Wobbrock. 2020. A systematic review of gesture elicitation studies: What can we learn from 216 studies?. In *Proceedings of the 2020 ACM designing interactive systems conference*. 855–872.

[77] Joshua Wade, Arpan Sarkar, Amy Swanson, Amy Weitlauf, Zachary Warren, and Nilanjan Sarkar. 2017. Process Measures of Dyadic Collaborative Interaction for Social Skills Intervention in Individuals with Autism Spectrum Disorders. *ACM Trans. Access. Comput.* 10, 4, Article 13 (aug 2017), 19 pages. https://doi.org/10.1145/3107925

[78] Verity Ward, Charlie Stone, Sarah Parsons, Hanna Kovshoff, and Ben Crump. 2022. Co-creation of research and design during a coding club with autistic students using multimodal participatory methods and analysis. In *Frontiers in Education*.

[79] James V Wertsch. 1985. *Vygotsky and the social formation of mind*. Harvard university press.

[80] David Wood, Jerome S Bruner, and Gail Ross. 1976. The role of tutoring in problem solving. *Child Psychology & Psychiatry & Allied Disciplines* (1976).

[81] Kirsty Yates and Ann Le Couteur. 2016. Diagnosing autism/autism spectrum disorders. *Paediatrics and Child Health* 26, 12 (2016), 513–518.

[82] Ga Eul Yoo and Soo Ji Kim. 2018. Dyadic drum playing and social skills: Implications for rhythm-mediated intervention for children with autism spectrum disorder. *Journal of music therapy* 55, 3 (2018), 340–375.

[83] Nicola Yuill. 2021. *Autism and Technology for Collaboration*. Springer International Publishing, Cham, 105–126. https://doi.org/10.1007/978-3-030-75047-3_6

[84] Nicola Yuill and Yvonne Rogers. 2012. Mechanisms for collaboration: A design and evaluation framework for multi-user interfaces. *ACM Transactions on Computer-Human Interaction (TOCHI)* 19, 1 (2012), 1–25.

[85] Nicola Yuill and Nicola Yuill. 2021. The Co-EnACT Collaboration Framework. *Technology to Support Children's Collaborative Interactions: Close Encounters of the Shared Kind* (2021), 1–19.

[86] John Zimmerman, Erik Stolterman, and Jodi Forlizzi. 2010. An analysis and critique of Research through Design: towards a formalization of a research approach. In *proceedings of the 8th ACM conference on designing interactive systems*. 310–319.

A PDW 1: MATERIALS

Skolen Sputnik & Aalborg University Workshops

Tuesday from 10:15 - 11:45
11th of April, 2023

Agenda

1. Meet & Greet: 10:15-10:30
2. Tech: Demo 10:30-11:00
3. Break: 11:00-11:10
4. Co-design: 11:10-11:40

Feedback

Which one did you like the most?

Best features?

Worst features?

What was or would be the most fun to play together, and why?

Co-Design

In the year 2098, the AI has taken over all music production, leaving humanity without the art of collaborative music creation.

You have been called upon as **distinguished scientists and engineers from planet Earth** to help rediscover the magic of co-creating music together.

Now that you have explored different music creation technologies and reflected on what you liked about them, it is time to **come together as a team** and create three groundbreaking design ideas for prototypes of collaborative music creation.

We are confident that with your collective brainpower, you will create something remarkable and possibly spark a **revolution in the world of music**.

Thanks for today!

Your name: ______________________________

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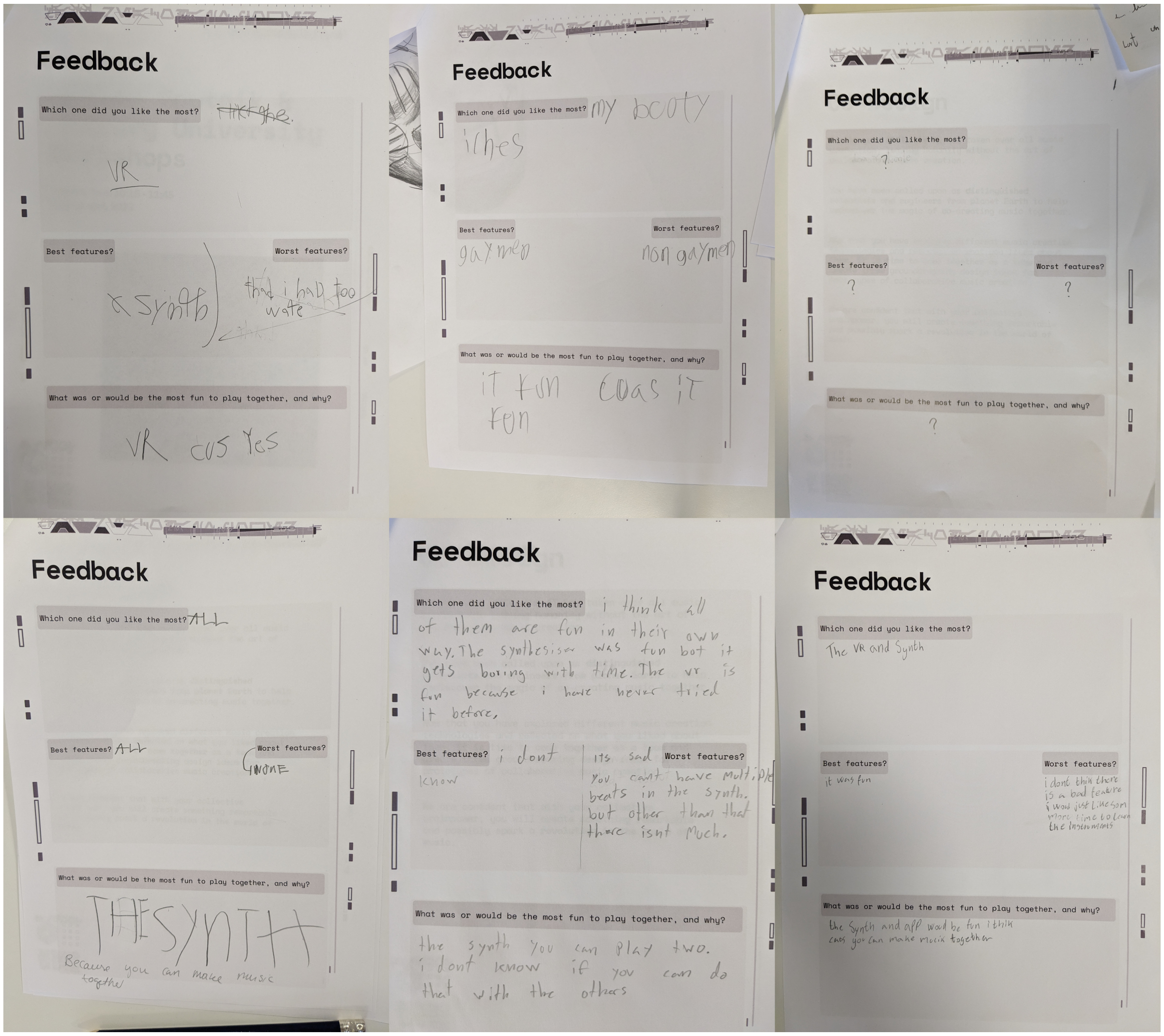

Fig. 16. Written reflections from the participants after interacting with three different audio technologies

B PDW 2: CODESNIPPETS

```
[0, 4, 7, 12] @=> int major[];
[0, 3, 7, 12] @=> int minor[];
48 => int offset;
int position;

fun void playTwoBars(int position, int chord[])
{
    2::second => dur beat;
```

```
    SinOsc osc => ADSR env1 => NRev rev1 => dac;
    (beat / 2, beat / 2, 0, 1::ms) => env1.set;
    0.2 => osc.gain;
    myReverbGain1 => rev1.mix;

    SinOsc osc2 => ADSR env2 => LPF filter => NRev rev2 => dac;
    env2 => Delay delay2 => dac;
    delay2 => delay2;
    (4::ms, beat / 8, 0, 1::ms) => env2.set;
    0.7 => osc2.gain;
    beat => delay2.max;
    beat / 16 => delay2.delay;
    myDelayGain => delay2.gain;
    myReverbGain2 => rev2.mix;

    myFilterFreq => filter.freq;
    myFilterRes => filter.Q;

    for(0 => int i; i < 4; i++)
    {
        Std.mtof(chord[0] + offset + position) => osc.freq;
        1 => env1.keyOn;
        for(0 => int j; j < 4; j++) {
            Std.mtof(chord[j] + offset + position + 12) => osc2.freq;
            1 => env2.keyOn;
            beat / 8 => now;
        }
    }
}
```

Listing 1. Implementation of a ChucK sequence of 4 arpeggiated notes on major and minor scales, based on a sine oscillator with various effects, such as Reverb, Delay, and Low-Pass Filter

```
public void AccelerometerDataHandler() {
    // Get accelerometer data
    Vector3 accelerometerData = Input.acceleration;

    // low-pass filter of accelerometer data
    smoothedAccelerometerData = Vector3.Lerp(smoothedAccelerometerData, accelerometerData,
    smoothingValue);

    // Map accelerometer data between 0 and 1 and to RGB colour
    float x_axis = Mathf.Clamp01(smoothedAccelerometerData.x + 0.5f);
    float y_axis = Mathf.Clamp01(smoothedAccelerometerData.y + 0.5f);
    float z_axis = Mathf.Clamp01(smoothedAccelerometerData.z + 0.5f);
    //Debug.Log("x-value: " + x_axis + "y-value: "+ y_axis + "z-value: " + z_axis);

    // Set object colour to bg
    backGround.material.color = new Color(x_axis, y_axis, z_axis);

    //remap values to handpicked effect parameters
    float delayData = Remap(x_axis, 0.0f, 1.0f, 0.0f, 0.7f);
    float reverbData1 = Remap(y_axis, 0.0f, 1.0f, 0.0f, 0.2f);
    float reverbData2 = Remap(y_axis, 0.0f, 1.0f, 0.0f, 0.4f);
    float filterData1 = Remap(z_axis, 0.0f, 1.0f, 10.0f, 10000.0f);
    float filterData2 = Remap(z_axis, 0.0f, 1.0f, 0.0f, 30.0f);

    //send values to chuck
    myChuck.SetFloat("myDelayGain", delayData);
    myChuck.SetFloat("myReverbGain1", reverbData1);
    myChuck.SetFloat("myReverbGain2", reverbData2);
    myChuck.SetFloat("myFilterFreq", filterData1);
    myChuck.SetFloat("myFilterRes", filterData2);
}
```

Listing 2. Connceting incoming acceleromter data from the iPhone to change audio effect's parameters in Chuck

C PDW 2: MATERIALS

Skolen Sputnik & Aalborg University Workshops

Tuesday from 10:15 - 11:45
18th of April, 2023

Agenda

Intro	10.15 - 10.30
Design Workshop	10.30 - 11.15
Break	11.15 - 11.25
Research Lab Fun	11.10 - 11.45

Written Feedback

What was your favourite part of the day?

Best part?

Worst part?

What was the most fun to do together?

Drawings

Thanks for today!

Your name: ______________________________

D PDW 3: CODESNIPPETS

```
//Button 1 looper
adc => LiSa loopme1 => Gain g1 => LPF filter1 => NRev reverb1 => dac;
                            g1 => Gain feedback => DelayL delay1 => g1;
//allocating memory in time
4::second => loopme1.duration;
//ramping for the edges of the recording so it doesn't clip
10::ms => loopme1.recRamp;

fun void recordSound1(Event start) {
    start => now;
    //loopme1.clear();
    //start recording input
    loopme1.record(1);
    //begin ramping down
    3600::ms => now;
    400::ms => loopme1.recRamp;
    //wait for ramp to finish, then stop recording
    400::ms => now;
    loopme1.record(0);
}

fun void playRecording1(Event start) {
    start => now;
    //set effeect parameters
    myPitch1 => loopme1.rate;
    myVolume1 => loopme1.gain;
    myFilter1 => filter1.freq;
    //start looping
    1 => loopme1.loop;
    //1 => loopme1.bi;
    1 => loopme1.play;
    while(true) {500::ms => now;}
}
```

Listing 3. Implementation of the LiSa sampler and looper in Chuck

```
// create a callback to use with GetFloar in Update()
myFloatSyncer = gameObject.AddComponent<ChuckFloatSyncer>();

// start syncing individual effect parameters
myFloatSyncer.SyncFloat(myChuck, "myPitch1");
myFloatSyncer.SyncFloat(myChuck, "myVolume1");
myFloatSyncer.SyncFloat(myChuck, "myFilter1");

myFloatSyncer.SyncFloat(myChuck, "myPitch2");
myFloatSyncer.SyncFloat(myChuck, "myVolume2");
myFloatSyncer.SyncFloat(myChuck, "myFilter2");

myFloatSyncer.SyncFloat(myChuck, "myPitch3");
myFloatSyncer.SyncFloat(myChuck, "myVolume3");
myFloatSyncer.SyncFloat(myChuck, "myFilter3");

myFloatSyncer.SyncFloat(myChuck, "myPitch4");
myFloatSyncer.SyncFloat(myChuck, "myVolume4");
myFloatSyncer.SyncFloat(myChuck, "myFilter4");

// start syncing global effects parameters
myFloatSyncer.SyncFloat(myChuck, "myDelay1");
myFloatSyncer.SyncFloat(myChuck, "myDelay2");
myFloatSyncer.SyncFloat(myChuck, "myReverb");
```

Listing 4. Connecting Unity variables in the C# script to Chuck global variables for the individual effects of all 4 LiSa sampler and loopers.

E CASE STUDY: ALTERED VERSION OF UMARS

Case Study Evaluation

Today you will try out a **collaborative musical experience** together using an iPad

Four people at a time will have **5 minutes** to **make a soundscape together**.

Afterwards, we ask you to **help us evaluate the prototype** by answering some questions.
There are a total of **13 questions** distributed four categories.

App Quality Ratings in terms of

a. Engagement
b. Functionality
c. Aesthetics
d. Subjective Quality

Circle the number that most accurately represents the quality of the app you are rating.

All items are rated on a 5-point scale from “1.Inadequate” to “5.Excellent”.

SECTION A

Engagement – fun, interesting, customisable, interactive

Q1

Entertainment: Is the app fun/entertaining to use? Does it have components that make it more fun than other similar apps?

1 Dull, not fun or entertaining at all

2 Mostly boring

3 OK, fun enough to entertain me for a brief time (< 5 minutes)

4 Moderately fun and entertaining, would entertain me for some time (5-10 minutes total)

5 Highly entertaining and fun, it would stimulate repeat use

Q2

Interest: Is the app interesting to use?

1 Not interesting at all

2 Mostly uninteresting

3 OK, neither interesting nor uninteresting; it would engage me for a brief time (< 5 minutes)

4 Moderately interesting; would engage me for some time (5-10 minutes total)

5 Very interesting, would engage user in repeat use

Q3
Customisation: Does it allow you to customise the settings and preferences that you would like to (e.g. sound, content)?

1 Does not allow any customisation or requires setting to be input every time

2 Allows little customisation and that limits app's functions

3 Basic customisation to function adequately

4 Allows numerous options for customisation

5 Allows complete tailoring the my characteristics/preferences, remembers all settings

Q4
Interactivity: Does it allow user input and provide feedback?

1 No interactive features and/or no response to user input

2 Some, but not enough interactive features which limits app's functions

3 Basic interactive features to function adequately

4 Offers a variety of interactive features, feedback and user input options

5 Very high level of responsiveness through interactive features, feedback and user input options

SECTION B

Functionality – app functioning, easy to learn, navigation, flow logic, and gestural design of app

Q5
Performance: How accurately/fast do the app features (functions) and components work?

1 App is broken; no/insufficient/inaccurate response (e.g. crashes/bugs/broken features, etc.)

2 Some functions work, but lagging or contains major technical problems

3 App works overall. Some technical problems need fixing, or is slow at times

4 Mostly functional with minor/negligible problems

5 Perfect/timely response; no technical bugs found

Q6
Ease of use: How easy is it to learn how to use the app; how clear are the labels, icons and instructions?

1 No/limited instructions; labels, icons are confusing; complicated

2 Takes a lot of time or effort

3 Takes some time or effort

4 Easy to learn (or has clear instructions)

5 Able to use app immediately; intuitive; simple (no instructions needed)

Q7

Gestural design: Do taps/swipes/pinches/scrolls make sense? Are they consistent across all components/screens?

1 Completely inconsistent/confusing

2 Often inconsistent/confusing

3 OK with some inconsistencies/confusing elements

4 Mostly consistent/intuitive with negligible problems

5 Perfectly consistent and intuitive

SECTION C

Aesthetics – graphic design, overall visual appeal, colour scheme, and stylistic consistency

Q8

Layout: Is arrangement and size of buttons, icons, menus and content on the screen appropriate?

1 Very bad design, cluttered, some options impossible to select, locate, see or read

2 Bad design, random, unclear, some options difficult to select/locate/see/read

3 Satisfactory, few problems with selecting/locating/seeing/reading items

4 Mostly clear, able to select/locate/see/read items

5 Professional, simple, clear, orderly, logically organised

Q9

Graphics: How high is the quality/resolution of graphics used for buttons, icons, menus and content?

1 Graphics appear amateur, very poor visual design - disproportionate, stylistically inconsistent

2 Low quality/low resolution graphics; low quality visual design – disproportionate

3 Moderate quality graphics and visual design (generally consistent in style)

4 High quality/resolution graphics and visual design – mostly proportionate, consistent in style

5 Very high quality/resolution graphics and visual design - proportionate, consistent in style

Q10

Layout: Is arrangement and size of buttons, icons, menus and content on the screen appropriate?

1 Ugly, unpleasant to look at, poorly designed, clashing, mismatched colours

2 Bad – poorly designed, bad use of colour, visually boring

3 OK – average, neither pleasant, nor unpleasant

4 Pleasant – seamless graphics – consistent and professionally designed

5 Beautiful – very attractive, memorable, stands out; use of colour enhances app features/menus

SECTION D

Subjective quality

Q11

Would you recommend this app to people who might benefit from it?

1	Not at all	I would not recommend this app to anyone
2		There are very few people I would recommend this app to
3	Maybe	There are several people I would recommend this app to
4		There are many people I would recommend this app to
5	Definitely	I would recommend this app to everyone

Q12

How many times do you think you would use this app as a break between classes the next 12 months?

1	None
2	1-2
3	3-10
4	10-50
5	>50

Q13
What is your overall (star) rating of the app?

1	☆	One of the worst apps I’ve used
2	☆ ☆	
3	☆ ☆ ☆	Average
4	☆ ☆ ☆ ☆	
5	☆ ☆ ☆ ☆ ☆	One of the best apps I've used

Further comments about the app?

THANK YOU!