Participatory Design of a Collaborative Accessible Digital Musical Interface with Children with Autism Spectrum Condition

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ABSTRACT

This research 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. Six PD workshops were conducted in collaboration with Stanbridge Academy (n=6) and Skolen Sputnik (n=6), incorporating fictional inquiry narratives and tailored non-digital activities. The resulting musical tablet app, '*boxsound*', prioritizes the user's perspective and enables the practice of various social skills by bridging divergent viewpoints. The CADMI was evaluated through a survey and semi-structured interviews with both children with autism and their educators.

Author Keywords

Accessible Instruments, Autism Spectrum, Participatory Design

CCS Concepts

•**Human-centered computing** → **Accessibility systems and tools;** •**Applied computing** → *Sound and music computing;* Performing arts;

1. INTRODUCTION

Worldwide it is estimated that one out of 100 children has autism spectrum condition (ASC) [31]. Autism is a diverse neurodevelopmental condition that can have a large effect on the physical and/or mental well-being of people with autism—common challenges faced are social interactions due to lack of emotional regulations [23], communication difficulties [20], repetitive patterns of behaviour [43]. 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 [32] can offer a quality of life improvement for individuals with autism, including more enjoyable social interactions [3, 34, 24] and an anxiety reduction [4].

This research explores and reflects upon the implementation of a participatory design (PD) process [36] involving two special educational needs (SEN) schools. We explore how PD can be applied to create a collaborative accessible digital musical interface (CADMI) [18] for children with ASC to facilitate collaboration and cooperative play among them, focusing on awareness of others and collaborative play. Research suggests that facilitating collaboration through technology for children with ASC is a well-established method [44]. We connect the significance of established music therapy [14, 21, 15, 13] and movement therapy [35, 38, 29] interventions to the role of collaborative social development and aim further to investigate this through a collaborative, exploratory PD process.

When working with children with neurodiversity, various factors, such as unequal power dynamics, diverse 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 [41] approach with a fictional inquiry [6] narrative to facilitate active participation. We attempted to minimize distractions by utilizing non-digital activities, inspired by *Handlungspielraum* [27] and the IDEAS framework [1].

The design process culminates in the creation of *boxsound* a tablet-app prototype that is grounded in theory and incorporates the diverse interdisciplinary perspectives of students, teachers, and academic professionals [33].

The main contributions of this participatory action research project are: (1) Detailing of the process of co-creating a CADMI prototype. (2) Interaction design paradigms for creating a shareable interface rooted in collaborative play methods and movement synchrony for children with ASC. (3) Insights from both children with ASC and their teachers on the effectiveness of a CADMI in an SEN setting.

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2. RELATED WORK

2.1 Collaboration Through Technology for Children with ASC

Yuill's Co-EnACT Collaboration Framework expands early theoretical perspectives on how social interactions shape children's development, proposing that the Vygotskian view of cultural artifacts shaping children's mental development can be connected to modern digital technology's impact on their advancement [42, 44]. Robinson et al.'s research on engagement in cooperative play defines five categories of participation in play, namely: solitary, onlooker, parallel-aware, associative, and cooperative. Additionally, Hornecker et al.'s notion of shareable capacities of technology can be used to identify points of transition between these fluid levels of participation [17]. These shareable capacities can be summarized into *entry points*, how a technology can invite interaction, and *access points*, how a technology invites individuals to interact with a group activity. These concepts offer insights into design affordances that minimize barriers to entry, offer diverse access, and maximize the fluidity of sharing, Hornecker et al.'s final access point needed in true collaboration where individual contributions are not necessarily distinguishable. Structure and constraint—or lack thereof—can morph ownership into a collaborative engagement [17].

2.2 Accessible Digital Musical Interfaces (ADMIs) for Children with ASC

Accessible Digital Musical Instruments (ADMIs), which entail specifically designed and customized DMIs created to allow the accessible use of digital music technology. In a recent review on ADMIs, Frid [12] finds that the use of music technology in music therapy contexts has seen an increased focus as of 2019. 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.

Based on the discovered research, most ADMIs created for ASC predominantly utilize tangible user interfaces (TUIs), sometimes in combination with a multisensory environment. The *Reactable* by Jordà et al. [19] offers an intuitive TUI for the collaborative creation of musical soundscapes. During a later study with nine ASC children [39], it was found to increase turn-taking behavior, suggesting the use of physical objects as a critical factor when facilitating interchanges and interactions with technological systems. Nonnis et al. developed *Mazi* [30], a TUI 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.

Förster et al. [7] developed two ADMIs designed for ASC children: *SnoeSky*, 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, and *SonicDive*, an ADMI installation that enables users to explore a complex water soundscape through their movement inside a ball pool. These ADMIs attempted to promote both relaxation and self-efficacy experiences, facilitated by a direct, and intuitive relationship between motion and sound. However, a desire for increased variation and complexity in the sound creation was expressed—as the *SonicDive* did not engender prolonged interactions. A combination of multisensory and TUI can also be found in *BendableSound* by Cibrian et al. [5], a system that facilitates neurological music therapy to improve the sensorimotor regulation of ASC children. Their prototype utilizes an elastic multisensory surface that plays sounds when touched. A formative study with 18 teachers found that *BendableSound* was both a usable and attractive method for interactive technological music therapy.

Within a multisensory environment, Lobo et al. [26] created a mobile system designed to support music therapists in teaching socio-communicative behaviors to children with ASC. *Chimelight* 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* increased engagement and decreased targeted negative behaviors.

Previous work has focused on extending collaboration as a critical aspect of the development of ADMIs. The development of *DuoRhythmo*, a system that empowers people living with Amyotrophic Lateral Sclerosis (PALS) to create music collaboratively in real-time, and the introduction of the term Collaborative Accessible Digital Musical Interface (CADMI) highlighted the significance of cooperation in creating meaningful technological experiences for accessible music-making situations [18].

2.3 Participatory Action Research with Children with ASC

Children with ASC have a breadth of diverse lived experiences and varying communication needs, preferences, and strengths. Therefore, adaptable data collection methods must be used to more accurately represent the child with ASC's contribution to the PD process. Ward et al. [41] argue that such an approach allows for a deeper understanding of the collaborative process and promotes a more inclusive design that better accommodates the needs and preferences of individuals with ASC.

PD offers a framework for working with marginalized groups often excluded from design processes [36]. Children with ASC are often subject to exclusion due to communication barriers and varied social abilities and preferences [2]. To better understand the value of participation, we seek to establish a collaborative, iterative PD process, drawing inspiration from Research through Design (RtD) [11] that includes children with ASC during the entire process. According to Zimmermann et al., [45], 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 research practice emphasizes 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. Makhaeva et al. suggests the concept of *Handlungspielraum*, a conceptual space in which creative co-design activities occur and emphasizes the importance of tailored conditions that enable the flexible exploration of the creative potentials of co-designers [27]. Kender et al. [22] propose employing diverse creative modes, such as Storyteller, Scientist, Actor, and Explorer, to involve children as co-designers in PD, prioritizing their needs and strengths. This approach encourages children's active participation and engagement in the creative brainstorming process through fictional inquiry. A significant branch of PD research is **participatory action research**, which aims "to encourage its co-designers to determine and critically evaluate a range of open (and perhaps non-design specific) issues if action research principles are used" [8]. Notable PD research projects include Benton et al.'s use of PD principles in the creation of the IDEAS framework as a method to involve children with ASC in the technology design process [1] and Frauenberger et al. extension of traditional research-based methods in its framework by offering a model to incorporate more context, designers' knowledge, and personal information about participants in the PD process [10].

3. METHODS

This project consisted of four principal components, namely: (1) introductory user research workshops (URW), (2) participatory design workshops (PDW) utilizing fictional inquiry, (3) evaluation case study with children with ASD assisted by their teachers, and (4) interviews with special educational needs (SEN) educators.

The iterative Participatory Design (PD) process involved two special needs education school classes as co-designers. During the URWs, we established an understanding and connection with our co-designers, using the IDEAS framework [1]. Based on the URW findings we further developed our methods framework to include participatory action research [41] combined with fictional inquiry [6]. The process was guided by the concept of Handlungspielraum [27], utilizing diverse creative modes [22] to create a conceptual space for creative co-design activities. Aiming to create an inclusive and empathetic connection with stakeholders, accommodating diverse needs, preferences, and strengths of individuals with ASC.

As part of our research, the students with ASC act as co-designers. We developed both workshop activities and design ideas iteratively and envelope them in an overarching narrative throughout the project phase. Using proxies in a PD process is a well-established method especially when collaborating with children. We draw on Moraveji et al.'s narrative framework [28] to immerse the co-design process in a futuristic narrative. Our narrative engages the co-designers in continuous roleplay throughout the workshop sessions, aiming to tap into their creativity, playfulness, and imagination to achieve a specific common goal and purpose. In a collaborative PD process, it is essential to shape the context of design workshop activities suggested by Dindler et al. [6]. Considering the diverse communication and collaboration preferences and abilities of children with ASC, a fictional inquiry framework could help bring together and onboard participants in the design process.

Despite following best practices, several difficulties in facilitating collaboration and participation in design activities were experienced in the URWs, leading to adjustments in subsequent workshops. Our study employs a user-centered PD process to develop a movement and audio-based experience to promote social abilities such as non-verbal communication and collaborative play. During a consultation with SEN teachers of both schools, we found potential in pursuing the design of a collaborative accessible digital musical instrument (CADMI) to empower children with ASC to engage in shared musical experiences. The prototype is designed for children with ASD in SEN schools as a "brain break" in between lectures, a concept suggested by the SEN teacher of Stanbridge Academy.

The prototype is evaluated through a case study with ASD children. The perceived engagement, functionality, and aesthetics during the case study are evaluated using the *Mobile Application Rating Scale: user version* (uMARS) [37]. While the uMARS scale did challenge the co-designers in terms of reading and rating each question, it was found by the SEN teachers to be the most likely method to produce some reflection and results from the participants. We made sure to allow for ample time to fill out the questionnaire and assisted in ensuring a thorough understanding of the question wording and answer options for the participants. Additionally, the effectiveness of the experience in enhancing social abilities is evaluated based on a post-interview with the SEN teachers.

4. USER RESEARCH WORKSHOPS (URW) AT STANBRIDGE ACADEMY

October - November 2022, San Mateo, California

The motivation for the URW conducted at Stanbridge Academy was to gain initial design insights as well as first-hand experience in working with neurodiverse children co-designers. We collaborated with a high school music production class, consisting of seven children with ASC. Following Benton et al.'s IDEAS framework [1], we organized three workshops at Stanbridge Academy: (1) Introductions and observation of preferred teaching methods, (2) Ice-breakers and brainstorming, and (3) Experimenting with several existing ADMIs.

4.1 Insights from URW

We applied playful PD methods to help the co-designers shift into a more creative mindset, which appeared to help some co-designers engage more deeply. The key takeaways from the URW were:

- **Understanding the Target Group**: Observing participants' interactions and responses informed our understanding of their capabilities and needs, shaping subsequent workshop designs.
- **Facilitating Creativity and Playfulness**: We emphasized fostering a creative mindset among co-designers. This exercise promoted creative thinking, highlighting the role of playful and imaginative activities in overcoming barriers posed by disabilities. We learned that it is essential to be adaptable in terms of the ASC participants' needs, desires, and energy levels,
- **Digital Music Workshops**: We presented collaborative and individual digital music experiences like *Shared Piano* and *Melody Maker* by Chrome Music Lab. Co-designers favored the quick generation of musical ideas, highlighting the potential for both collaboration and individual expression.

Contextualizing the design challenge is crucial for engaging co-designers, helping them gauge the feasibility of presented ideas. Introducing existing digital musical experiences enabled them to comprehend the project's potential, inspiring creative contributions. Feedback and observations enhanced our understanding of participants' abilities and interests, guiding future workshop designs. Recognizing challenges, like the use of open-ended questions, and lack of structure for active engagement, prompted adjustments in subsequent workshops.

5. PARTICIPATORY DESIGN WORKSHOPS (PDW) AT SKOLEN SPUTNIK

April-June 2023, Copenhagen, Denmark

The structure of the PDW was designed to actively leverage the co-design processes and participatory prototyping. Through tech demo sessions and design thinking role-play sessions, the workshops aimed to provide a platform for the children to express their opinions in a supportive environment.

Participation in the workshops was voluntary, and teachers selected a class with expected enthusiasm for the research. The school's flexible participation approach meant anticipating four to six co-designers per session. Consequently, we devised an adaptable workshop structure to accommodate varying participation levels each day.

5.1 Workshop 1: Context Setting

We focused on crafting a narrative structure, influenced by insights from relevant literature on conducting workshops with neurodiverse children. Drawing on previous work [27, 28], an introductory pre-recorded video set the narrative tone, followed by three technological experiences and a written reflection task. To minimize disruptions, the session avoided external screens and technologies.

A purpose-designed pamphlet aligned with the narrative served as a guide for participants, outlining the day's agenda, narrative details, and reflective writing tasks. Post-technology demonstrations, participants engaged in written reflections, enhancing the feedback process. A roleplay session, preceded by a superhero mask exercise[1], led to the generation of three collaborative musicking conceptual design ideas, with a heightened focus on time management.

The tech demo segment featured demonstrations of audio technologies—*PatchXR*[2], *Koala Sampler*[3], and *DatoDuo*[4]. Evaluation sheets and an open discussion unveiled varying participant engagement, providing valuable insights into their perceptions of the technologies. Following a break, co-designers assumed fictional characters, presented as cards, but encountered challenges in roleplaying, necessitating increased facilitation by the workshop conductor. With support, a compelling conversation ensued, leading to the conceptualization of four ideas.

1. **Online**: An environment where you could tap in and out of other people's soundscapes with 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.

5.1.1 Results

In the first PDW session, insights from the URW were applied to enhance inclusivity in co-designer participation. The superhero mask activity served as an effective icebreaker, fostering enthusiastic engagement in the tech demonstration. Notably, collaboration around the *DatoDuo* was a standout, showcasing seamless role-switching and participatory musicking. Stations for *DatoDuo* and *PatchXR* offered diverse experiences, with the former attracting collaborative play.

Despite the success of the tech demo, the brainstorming phase encountered challenges due to its open-ended nature. Co-designers expressed confusion and the need for clearer tasks and guidelines, as exemplified by one participant's uncertainty about embodying the assigned character. In the reflection session, T1 introduced a collaborative iPad streaming idea, leading to discussions on split-screen interfaces, competition, voting, and the integration of personal vocal samples. The importance of clear guidelines for effective ideation was underscored, with the split-screen concept and personal vocal sample integration gaining interest among co-designers.

5.2 Workshop 2: Prototyping

Before the second workshop, insights from the first session were synthesized into design goals, with a focus on enhancing collaboration through movement. Inspired by discussions following the PDW1 tech demo, a hypothesis emerged to incorporate a form of bodily movement into the experience. S1 expressed interest in an experience that subtly encouraged movement, particularly as he was not keen on physical activities.

The project's initial phases pondered the setting, context, duration, and participants for the experience. Drawing from URW data, the concept of a "brain break" was chosen. SEN teachers often faced motivational challenges, and Teacher 1 (T1) highlighted his students' limited physical activities. A "brain break" aimed to offer co-designers a rejuvenating experience, providing an opportunity to recharge. T1 emphasized the importance of easy entry and exit from the experience.

Exploring the integration of body movements into music creation, the team recognized the potential of embodied control for musical parameters as a playful approach aligned with movement therapy principles. Noting co-designers' enjoyment of the sampler in the first workshop, three participatory prototyping exercises were designed. These exercises investigated collaboration, natural embodied gestures for sonic parameter changes, and showcased an extension of the sampler app from PDW1 called *Tone Transfer* [5].

5.2.1 Design of Prototypes

To explore collaboration through a cardboard prototype, inspired by a gesture elicitation study, we aimed to observe co-designers reaching a consensus on a shared gesture-based command for sound control. Using a rectangular box with painted buttons emulating a shareable touch interface, the prototype employed a split-screen interaction paradigm discussed in PDW1. Co-designers, by holding and pressing buttons, collaboratively adjusted parameters while generating audio snippets with *Ableton Learn Synth Playground* [6].

For the phone prototype, we sought to validate assumptions about incorporating physical movement and using movement as an embodied sonic parameter controller. In Unity[7] with *ChucK*[8] for audio, the low-fidelity prototype utilized

[1] https://gamestorming.com/ice-breaker/
[2] https://patchxr.com/
[3] https://www.koalasampler.com/
[4] https://dato.mu/
[5] https://sites.research.google/tonetransfer/
[6] https://learningsynths.ableton.com/
[7] https://unity.com/
[8] https://chuck.stanford.edu/

the phone's accelerometer to alter audio effect parameters in a musical loop along the X, Y, and Z axes.

Drawing from the methodology of a gesture elicitation study by Wobbrock et al. [40], we assessed both prototypes. Co-designers proposed gesture-based commands to trigger specific effects, aligning with the study's approach to designing movement-based interactions. Notably, Leng et al. found limited user agreement when defining sonic gestures in gestural interface design for music interaction, emphasizing the complexity of defining such interactions [25].

5.2.2 Results

The *Tone Transfer* application showcased during the workshop revealed the co-designers' creativity and expressiveness, with participants enjoying collaborative sound creation using various props. The phone prototype, employing embodied interaction techniques, intrigued co-designers as they transformed body movements into sound effects. However, they encountered challenges with slow response times and suggested improvements for clearer instructions and faster feedback. Co-designers brainstormed collaborative features, including freezing beats and recording voices for musical compositions.

The cardboard prototype, simulating digital sound recreation, prompted creative and adaptive approaches, with some co-designers expressing a desire for more communication time. Emphasizing the importance of an inclusive environment, the workshop received positive feedback from SEN teachers, indicating its success in meeting co-designers' needs and fostering a supportive learning environment. The workshop's appropriate length and the novelty of the research team's visit contributed to co-designers' engagement and a positive learning experience.

5.3 Workshop 3: Case Study

16th of May 2023, Copenhagen, Denmark

The goal of this session was to understand the impact and evaluate the created prototype in a contextualized scenario. Once the co-designers were familiarised with the prototype, we introduced the narrative concept of creating a time capsule. The goal was to record and share this capsule in the future, enabling the role-playing narrative introduced in PDW1. 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 utilized an adapted version of the uMARS questionnaire. Additionally, we conducted a semi-structured interview with the two SEN teachers. The interview explored the potential relevance of incorporating a prototype-like product into their regular school day.

5.3.1 Design Concept

To prepare for the third workshop, an analysis of insights from the second workshop was conducted. This synthesis aimed to distill the knowledge into tangible design goals. The evaluation of the phone prototype highlighted the importance of swift and responsive sonic feedback and the need for more obvious sound effects for embodied sonic exploration. The cardboard box exercise confirmed that a shareable tool for modulating sound effects could be enjoyable for the co-designers, but the challenge lies in translating that enjoyment to a sharable iPad interface. Clearly defined separate play areas and intuitively designed controls for simultaneous interaction are essential. Inspired by the success of the *ToneTransfer* demo, implementing an intuitive and performative live sampler and looper is necessary. Individual controls should be provided to allow co-designers to tweak their recordings and shape them into pleasant and musical sounds.

5.3.2 Design and Implementation

To effectively cater to a digitally native target group, a high-fidelity prototype with attention to detail is crucial. Friendly and playful colors and shapes might establish an emotional connection with the co-designers, enhancing their engagement and ownership towards the interface. A retro-futuristic aesthetic for the audio-visualiser was selected to tie the interface into the PD process narrative. Furthermore, the design language could highlight the interface's resemblance to musical devices, featuring instrument-like visual cues that promote familiarity.

When designing the high-fidelity interface GUI, the challenge was to provide an intuitive metaphor for shareable interactions. The prototype was designed for four people's collaboration, utilizing the iPad's physical capabilities and assigning one player to each corner. Individual play areas and the ergonomic layout of controls were prioritized. The recording button, a key interaction, was placed prominently in the corner for easy reach. Dedicated colors were assigned to each corner to enhance ownership and distinguish roles. Touch-controlled knobs and sliders were used for effect controls, placed within reach of one finger while holding the iPad.

The prototype's audio engine utilized live sampling. The mechanics of effects were adjusted based on co-designers' feedback, ensuring swift and responsive sound changes. Individual effect controls allowed co-designers to tailor their recordings and take ownership of their sonic expressions. Three effects were implemented: playback rate, volume, and a low-pass filter. An audio-visualizer provided comprehensive visual feedback of the playing sonic field Figure 1. All of these design elements were incorporated into the creation of the *boxsound* prototype, so named by one of the PDW co-designers.

5.3.3 Evaluation

In a case study at Skolen Sputnik involving four co-designers with ASC, two SEN teachers, and two researchers, the prototype's functionalities were introduced at a round table. The co-designers explored recording voiceovers, focusing on spoken sounds, internet memes, and unconventional sounds. After a shift in approach and the departure of one co-designer, they incorporated device movement to add effects to the soundscape, with close proximity posing a challenge for some. Creating a rhythmic composition using various objects and non-verbal vocals, co-designers adjusted pitch, tempo, and volume to shape the mood.

The recording session concluded with co-designers holding the device together, instinctively moving in different directions to synchronize with the evolving soundscape. Expressing fascination, one co-designer remarked, *"It sounds like we are walking into another dimension!"* Following the session, a group review of the questionnaire allowed each co-designer to reflect and provide feedback on engagement, functionality, aesthetics, and subjective quality. R2 and T1 guided the process, adapting the questionnaire for the application. Table 1 displays individually calculated and average scores of the uMARS subscales for App Quality.

In the follow-up interview with the teachers, we aimed to gain insights into their perspectives on using the prototype as an app during school breaks. Initially, they found

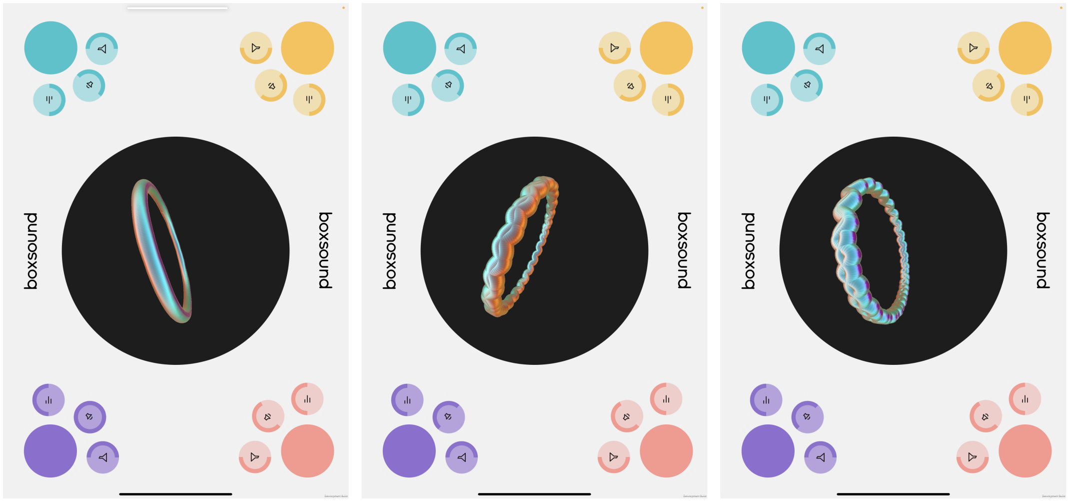

Figure 1: The audio-visualiser component in its default state (left) and in different stages reacting to various sounds

the app's features captivating, with T1 noting it could be a fun conversation starter tool. T2 emphasized the challenges children with ASC face in interaction and communication. This led to discussing the possibility of including a music teacher or therapist to guide the co-designers in exploring sounds and understanding musical composition. T2 also highlighted the importance of intrinsic motivation and shared goals in engaging co-designers, suggesting that either a clear motivation to create music or a structured environment with a facilitator could enhance the experience. T1 suggested recreating a favorite song together as a goal, while T2 proposed distributing roles or creating sound stations to make it easier for co-designers to participate.

6. DISCUSSION

6.1 Usability Considerations

The participatory design (PD) process for "boxsound" followed an iterative approach, incorporating insights from therapeutic practices and collaborative technology theories. The URW provided valuable insights into effective approaches for involving children with ASC in the design process. The PDWs established a robust framework for conceptualizing a prototype aimed at fostering social, collaborative, and communication abilities.

The prototype demonstrated commendable functionality and received positive feedback from co-designers and teachers. The user interface was intuitive, and response times were generally satisfactory, minimizing frustration. However, identified areas for improvement include the accuracy of the recording button, refinement of effects, the inclusion of a play/pause or global mute option, and the need for clearer guidance in creating specific scenarios for sound corners. Additionally, suggestions were made for features like export/save functionality and an import mode.

6.2 Collaboration and Movement for Children with ASC

The conceptual goal was to facilitate collaboration through a shareable interface and movement synchrony. The iPad's design allowed simultaneous multiplayer action, enabling co-located collaboration. The interface design with individual play areas facilitated simultaneous co-located collaboration, and co-designers understood and used the prototype accordingly. However, a more explicit collaboration metaphor or guided collaboration approach might have enhanced engagement, especially for those lacking intrinsic motivation.

The absence of a guided collaboration metaphor extended to the movement aspect. Co-designers showed limited inclination to adjust sonic parameters with body movements, indicating the need for a more constrained collaboration model or the involvement of a music/movement therapist to enhance the exploratory approach. The current exploratory collaboration might be more suitable for participants with shared composition goals or additional musical experience.

6.3 Challenges with Shareable Interface

Using the iPad as a shareable interface posed challenges, as some co-designers were not close friends, leading to discomfort when physically close. The suggestion to avoid simultaneous physical contact with the device resonates with concerns about the potential intimidation it might pose for some co-designers in this specific group.

The examination of usability considerations and collaboration aspects provides insights into the strengths and potential enhancements for the "boxsound" prototype. Addressing identified areas for improvement and considering a guided collaboration model could optimize the experience for children with ASC. The challenges with the shareable interface highlight the importance of tailoring design choices to the comfort and preferences of the specific user group.

6.4 Key Insights from Conducting Participatory Action Research Methodology

Participatory action research in the development of unconventional technological prototypes demands adaptability and compromise. Holone et al. [16] stress the importance of shared vocabularies, trust-building, addressing communication barriers, and empowering co-designers with ASC in decision-making. Our workshop sessions often deviated from expectations, emphasizing the difficulties in empowering all neurological diverse participants to contribute [9].

User research workshops (URW) prepared us to engage effectively with co-designers with ASC, using introduction games to build trust and embracing Handlungspielraum principles [27]. Specific strategies, including a structured environment, visual supports, and clear communication, aligned

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 1: Scores from the uMARS questionnaire based on the case study of the prototype, ranging from one to five, with higher scores indicating better quality.

with Makhaeva et al.'s recommendations [27]. Insights from Stanbridge Academy, such as the impact of workshop timing on engagement, informed adaptations for planning sessions with Skolen Sputnik.

Collecting feedback from children with ASC involved flexibility [27, 41]. Initially, open-ended questions yielded limited responses, leading to a narrative-based approach inspired by Moraveeji et al. [28]. A fictional narrative, featuring roleplaying cards and a recorded video, contextualized the workshops. However, the complexity of combining roleplaying and design thinking overwhelmed some codesigners. In response, we refined the narrative approach, simplifying the roleplaying element to reduce cognitive demands while maintaining contextualization [41].

7. CONCLUSION

This research project focuses on addressing challenges faced by children with Autism Spectrum Condition (ASC) by developing a Collaborative Accessible Digital Musical Interface (CADMI) through a Participatory Design (PD) process. The objective is to foster collaboration, cooperative work, and communication skill development among children with ASC through a technological musical co-creation prototype, *boxsound*. Employing a participatory action research approach, the project utilizes fictional inquiry narratives and non-digital activities, adapting continuously to harness the unique strengths of individuals with ASC. The primary contributions include the collaborative creation of the CADMI prototype, the introduction of interaction design paradigms grounded in collaborative play methods through shareable interfaces, and insights from SEN teachers and children with ASC regarding the prototype's effectiveness in a SEN school setting.

In summary, this project provided valuable insights into technology co-creation for children with ASC, emphasizing collaboration, communication, and social development. Integrating theoretical foundations, participatory design approaches, and interdisciplinary perspectives contributes to the knowledge base in PD and CADMI, aiming to enhance the lives of children with ASC and inspire future research endeavors.

8. ACKNOWLEDGMENTS

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9. ETHICAL STANDARDS

This research was conducted under ethical clearance and approval of Aalborg University.

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