Finding resilience through music for neurodivergent children

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Abstract

This research paper presents a collaborative effort to design a music-making tool that seamlessly blends enjoyment with accessibility, specifically tailored to meet the needs of children with diverse abilities including those who are neurodiverse and have varying musical abilities. The study's primary objective is to provide support to children who encounter challenges in learning traditional musical instruments or who have sensory processing issues and learn their experience of using this tool. Additionally, the research explores the potential role of music therapy in this context, with a focus on how the designed tool can serve as an ideal platform for fostering creativity and self-regulation among children.

Qualitative research methods, namely participatory design and cooperative inquiry, were employed to develop and refine different aspects of the music-making tool iteratively. Active involvement and feedback from the primary participants, comprising children with diverse abilities and a music therapist, played a central role throughout the tool's development process.

The findings indicate that children responded positively to the technology, revealing diverse applications in music education, therapy, and play. Furthermore, this study identified valuable opportunities for immediate improvements in the robot's design to enhance its overall usability and effectiveness in catering to the needs of its users. The collaborative design approach and the integration of music therapy perspectives demonstrate significant potential for advancing inclusive music education, play and therapeutic interventions for children with diverse abilities.

Acknowledgment

I am deeply grateful to the diverse array of experiences both in my personal and professional life that have shaped and inspired the selection of this research topic. The journey that led me to delve into designing for children and inclusive design has been both enriching and enlightening. Every encounter, every obstacle, and every triumph has contributed to the realisation of this research project.

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Dedication

This research report is dedicated to individuals who have often felt like misfits, tirelessly striving to make sense of their unique likes, dislikes, characteristics, and overall life journey. To those who dare to dream beyond the confines of societal norms, challenging conventions and bringing vibrant colours to a sometimes monochromatic world. In a world that often seeks conformity, you stand tall as the beautiful anomalies, weaving threads of individuality into the fabric of humanity in extraordinary ways.

This research is for you—the resilient souls who are unafraid to embrace their uniqueness and who persist in finding their voice and place. May this research shed light on the beauty and strength that lie within your differences and remind you that your presence in this world is essential. As you navigate the complexities of life, may you find solace, inspiration, and affirmation in the understanding that being different is not a flaw but a gift to be cherished and celebrated.

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1 Introduction

The effects of technological play on children have been extensively researched. Several studies have provided insights into the impact of digital media and technology use on infants, toddlers, and preschoolers, as well as the associations between media exposure and cognitive development, behavioral difficulties, and parent-child interactions.

Vandewater et al. (2007) and Zimmerman et al. (2007) highlight the prevalence of media such as watching TV, videos, DVDs etc among young children and emphasize the need for informed choices and parental involvement in screen time. Anderson & Subrahmanyam (2017) discuss the impact of digital screen devices on cognitive development. They note that young infants and toddlers are using touch screen devices, but little is known about their comprehension of the content.

Considering the existing landscape of digital media aimed at children, the researcher conceived a music-reading and writing interface designed specifically for neurodiverse children. The aim was to create a tangible solution that circumvents screen time while harnessing the multisensory aspects of diverse media – auditory, tactile, and visual.

The research attempted to answer the following research questions and hypotheses that have been formulated:

1. In what manner can the design of an accessible music writing and reading interface be enhanced to cater to the needs and preferences of neurodivergent children aged six to twelve years?

2. How can a tangible interface, developed to create melodies, aid neurodivergent children in self-regulating and utilizing it as an instrument for creative expression?

This music interface employs vibrant LEGO blocks as visual inputs, producing audio outputs corresponding to musical notes. The methodology section of the report provides an extensive description of this interface.

Comprehending the research in a more profound manner necessitates a social perspective on neurodiversity, as expounded by Frauenberger et al. (2018). Neurodiverse individuals commonly encounter learning challenges, cognitive limitations, and intellectual as well as developmental differences. These factors significantly affect their executive functions, memory, cognitive capabilities, and communication aptitude. This study by Frauenberger et al. (2018) suggests that commencing the design of technology for neurodivergent children from a standpoint of presumed deficits not only confines the potential scope of design but also introduces ethical and moral inquiries concerning our perception of disability within society. The research endeavoured to delve into alternative avenues for conceptualizing technology intended for autistic individuals and asks important questions such as how media technologies can undertake diverse roles, carrying significance beyond mere assistance.

Leo Kanner's (1943) investigation of the role of musical processing abilities in the lives of individuals with autism further shapes the role of music within the prototype that is designed by the researcher. Research on music and sound-based activities has also shown promise in supporting neurodiverse children's development and emotional regulation (Marti et al., 2009).

Combining this comprehension of music with the application of interactive technologies in therapeutic and rehabilitative approaches for neurodiverse individuals (Marti et al., 2009) expands the horizons of this research. With this, the upcoming research explores the impact of the prototyped music reading and writing interface by incorporating tangible elements like LEGO blocks into the music interface. The research aims to contribute to the design of inclusive technologies that support neurodiverse children's emotional and cognitive development, promoting a more inclusive and accepting society. The involvement of children and music therapists in the co-design process was valuable as it offered important insights into the potential of the interface.

This study is significant because there is a shortage of music-based treatments for neurodiverse children that incorporate technology in a discreet manner and are beneficial for kids without any formal training in playing a musical instrument. An interactive platform like this and its assessment with children with varying abilities provides insight into the potential of such tactile, non-screen technologies for kids.

The literature review section of this study delves into the current state of knowledge regarding the intricate relationship between neurodiversity, music engagement, tangible interaction and self-regulation. Moving forward, the methodology section examines the research design employed, the theoretical framework used, the approach to reviewing and interpreting findings, and the methods of data collection and analysis utilized. This research uses participatory methods, specifically Cooperative Inquiry to involve neurodivergent children and music therapists in the design process.

The ensuing section provides a comprehensive write-up of the results and discussions combining Actor-Network Theory and Critical Discourse Analysis to define important themes from the co-design sessions, followed by future possibilities, and limitations, culminating in a conclusion that marks the conclusion of the research endeavour.

2 Literature Review

2.1 What are neurodiverse children like

Learning differences in children and adolescents can be diagnosed as autism, dyslexia, and ADHD (Kentrou et al., 2018). According to (*Data and Statistics on Autism Spectrum Disorder | CDC*, 2023), approximately 2.8% of children in the United States fall under the autism spectrum disorder (ASD), which is significant among the child population.

Neurodiverse conditions encompass learning difficulties (Brosnan et al., 2017), cognitive impairments, and intellectual and developmental disabilities (Benton et al., 2014), such as Attention-Deficit Hyperactivity Disorder (ADHD) and autism Spectrum Disorder (ASD). Such disorders affect up to 7% of the population (De Santana et al., 2013), impairing individuals' executive functions, memory, cognition, and communication skills. Such limitations hinder individuals' abilities to self-regulate, perform daily activities independently, and to maintain interpersonal relationships (Liu et al., 2021; Scandurra et al., 2019). Self-regulation here refers to the differences in how neurodiverse individuals regulate their emotions, attention, and behaviour. Studies suggest that neurodiverse children may struggle with recognizing and understanding their own emotions and those of others, difficulties in inhibitory control and sustained attention (Mazefsky et al., 2013; Samson et al., 2014; Barkley, 1997; Nigg, 2017).

Among children, these conditions are frequently termed 'abnormalities' (Al-Mosawi, 2020) of the brain. Understanding neurodiversity through a social standpoint captures these conditions as natural differences in the human brain and attempts to alter the view that these differences are problems to deal with. (What is Neurodiversity, n.d.). Studies by Andreano & Cahill (2009) and Frost et al., (2015) on the brain have shown that individuals with learning or thinking differences are born with neuron systems that think, learn and process information differently than others. Roberson et al. (2021) explore that neurodiversity can lead to positive behaviours among those diagnosed with it and understand their differences not as faults but simply as ways in which they are unique. These attitudes among children make them better prepared to handle their uniqueness throughout their lives.

Judy Singer, an Australian sociologist, coined the term neurodiversity to support equality and inclusion for "neurological minorities." The neurodiversity movement in 1990s helped promote this acceptance and inclusion of all individuals, regardless of neurological differences. With the help of online platforms, autistic individuals were able to connect and form a self-advocacy movement (Baumer & Frueh, 2021). Although it is primarily a social justice movement, neurodiversity research and education play an increasingly important role in how different practitioners approach certain disabilities and neurological conditions (Baumer & Frueh, 2021).

While neurodiversity encompasses a range of neurological conditions, it is important to recognize that it extends beyond autism and includes various other conditions that affect individuals' cognitive and learning processes (Clouder et al., 2020; Roy & Jain, 2020). In educational settings, particularly in classrooms, neurodiverse children may face challenges in participating fully (Hamilton & Petty, 2023). These challenges can arise due to the unique ways in which neurodiverse individuals perceive, learn, and interact with the world (Hamilton & Petty, 2023). For example, individuals with autism may struggle with social interactions and communication, while those with ADHD may have difficulties with attention and impulse control (Nuske et al., 2018).

With that, there is also an understanding that children on the spectrum tend to be introverted (Corbett et al., 2010). Children who identify as neurodiverse have reported struggling with many aspects of everyday life that hamper their social communication, interaction with their peers, social reciprocity and other nonverbal communicative behaviours used for social interaction, and skills associated with developing, maintaining, and understanding relationships (Corbett et al., 2010).

Navigating through neurodiverse conditions can pose challenges for children, yet it also comes with its unique strengths. When Leo Kanner (1943) first reported autism in his research in 1943 with eleven case studies of children with autism, he repeatedly mentioned musical abilities and musical interests in six of the children (Molnar-Szakacs et al., 2020). Since then, researchers such as Molnar-Szakacs et al. (2020) and Grove et al. (2018) have regularly tried to investigate the role of musical processing abilities in the lives of individuals with autism. These studies have shown that while language skills may sometimes be deficient, these individuals process music similarly to typically developing individuals. The most important verification supporting the benefits of music lies in social-emotional responsiveness, including reduced anxiety, improved speech output, receptive labelling, and increased interaction with peers (Molnar-Szakacs et al., 2020; Grove et al., 2018).

Music educators who have worked with neurodiverse children have explained that the children they teach have a flair for music. Michael Thaut, a music therapist, believes that "Children on the autistic spectrum often have a remarkable capability and responsiveness to music as compared to most other areas of their behaviour, as well as in comparison with typical children” (Hourigan & Hourigan, 2009, p. 41). This tells us that the challenge for music teachers or those interested in developing regulatory tools for children is to identify how to tap into this musical responsiveness amid all the other distractions that arise in the life of a neurodiverse child (Lim, 2010; Niedenthal et al., 1999).

2.2 Engaging with music

A group of researchers have found that music training, particularly piano lessons, can greatly improve children's abstract reasoning skills. Engaging in musical activities can assist children in developing physical coordination, timing, memory, visual, aural, and language skills. Learning and practicing music with others can also help children improve their self-paced learning, mental concentration, and social awareness (Forgeard et al., 2008; Gordon et al., 2014).

Countries with high academic achievements such as Hungary, Netherlands, and Japan have prioritized music education in their curriculum. They have been providing both instrumental and vocal music training to elementary and middle school students for many years. This emphasis on music education contrasts with the United States' emphasis on math, science, vocabulary, and technology (McKinnon, 2005).

The idea that learning music can make a child smarter has gained considerable attention from parents, educators, and policymakers. Children with autism have steadily shown uncommon sensitivity and attentiveness to music (Kanner, 1971; O'Connell, 1974) and often respond with positive affirmations to music and sound vibrations such as those coming over a radio (Nelson et al., 1984). This has further led many researchers to investigate the use of music to improve their atypical behaviours. Burleson et al. (1989) tested a hypothesis that musical abilities can increase precision within a task and enhance focus in children with autism.

Music comprehension and creation employs multiple areas and networks of the brain involving sensory, motor, emotional, attentional, and social processes in a way that these experiences may transfer to non-musical skillsets due to shared neural resources (Patel, 2011; Wan & Schlaug, 2010).

Meadows (1997), who conducted research on music therapy for autistic children, identifies six main goals of this therapeutic approach. These goals include fulfilling the child's basic needs, which lays the foundation for further development. The process also emphasizes the growth of the child's sense of self, which is vital for personal identity and self-awareness. Additionally, music therapy can aid in establishing or re-establishing interpersonal relationships, a critical aspect of social integration. Development of specific skills tailored to the individual's needs is another core objective, along with the dispelling of pathological behavior, which can hinder the child's progress. Finally, the approach fosters an appreciation and sensitivity to the beauty of music, enriching the child's cultural and aesthetic experiences.

Symbolic play such as musical play is another context for children across developmental ability levels to be involved in social attention, language and motor activities to help reach goals in other areas and disciplines (Kasari et al., 2012). Some neurodiverse children may also present an intuitive ability to recreate and remix a musical inspiration that furthers the understanding of their adeptness with music (Lense & Camarata, 2020).

Exploration of the use of music in research by Kern & Wakeford (2007) at the time of morning drop-off to childcare positively improved the children's functioning and overall engagement with their peers. This context focuses on the benefits of wider music applications in everyday life. They also showcase a growing interest in research and education that identifies the natural diversity of neurocognitive functioning and looks for support for these variations without attempting to "fix" autistic behaviours (Kapp, 2020).

While there is a growing concern for the neurodiverse population, especially children and the role of music towards their well-being, there is also a lack of qualitatively researched music interfaces or tools for these children in regulating and promoting their well-being. The role of music as a communicative and regulatory tool is often acknowledged in music therapy, but it needs to be given more attention in informal and personal contexts. Learning to play an instrument is mentally challenging and is often thought of as something that must happen with a teacher. Designers can make it easier for neurodiverse children to experience the benefits of music-making by creating a system that creates a starting point for children to foray into formal music theory practice. Collaboration among designers and music practitioners is key to achieving this goal.

2.3 Self-Regulation among neurodiverse children

To be able to better control their emotions, it is required so that children feel good and relaxed to better regulate at any given time of the day (Foothills Academy, n.d.). The early years of a child's life are crucial for developing self-regulation that consists of an array of complex mental capacities such as impulse and emotion control, self-guidance of thought and behaviour, planning, self-reliance, and socially responsible behaviour (Bronson, 2000; Kopp, 1991).

Before the preschool years end, children who are good at regulating their behaviour can wait for their turn in a group, manage the temptation to disturb a peer, clean up after themselves, be willing to support another child and most importantly, persist in strenuous activity. These examples show us how self-regulation is central to our conception of the foundation for choice and decision-making, mastery of higher cognitive processes, and morality. Children who can self-regulate find it easier to meet personal and social expectations (McLean, 2018).

Poor self-regulation can drive emotional and behavioural disorders, arousal disorders, activity levels and sleep–wake cycles (Hagan et al., 2016). This is even more difficult for children who identify as neurodiverse as their ability to self-monitor, anticipate outcomes and reliably link their actions to consequences is often compromised (Johnson, 2012; Tranj et al., 2011). They may need specific sensory regulation strategies to assist them. These processing strategies can help them practice sustained concentration and focus through different modalities. Such resources and measures can come in handy for neurodiverse children to better self-regulate, which essentially means the reduction of fatigue, worry, and agitation; improved stress resistance; and heightened abilities to overcome hesitation and fear (Kalimullin et al., 2016).

Several interventions have been worked on to enhance such technological developments. In research conducted by Diamond & Lee (2011), the common features of these programmes are the planning of self-regulation activities, the importance of play, and engaging children's autonomy and agency. Within play episodes, children get to develop skills that are fundamental to self-regulation (Hawes et al., 2012) as it allows them to think flexibly, have goals and learn to negotiate and cooperate with peers, all this while focusing on a particular task (Baumeister & Vohs, 2011).

2.4 Neurodiversity and technology

The concept of interactive technologies and robotics is undergoing a surprising expansion within the sphere of children's play. In recent years various types of robotic tools have been used for therapeutic and rehabilitative purposes. Robots specifically designed to stimulate social exchanges have been used to support the cognitive development and maturation of children with socio-relational disturbances, from slight linguistic retardations to Down Syndrome (Pollini et al., 2005; Marti., 2006), and from developmental retardations to relational deficit problems such as autism.

Various experiments have been conducted to examine the therapeutic benefits of using robots to treat autism. This is due to the observation that individuals with autism find enjoyment in interacting with computers (Powell, 1996). Social robots have been developed to target children who are unable to play due to various impairments, which can hinder their learning potential (Kanero et al., 2018; Park et al., 2019). Furthermore, interactive environments, such as the PLAYWARE playground, have been designed to cater to the needs of users and promote play and therapy in rehabilitation settings (Lund & Jessen 2005). It is made up of tangible tiles, which functions as a building block by containing processing power, sensors, actuators, and communication capabilities. It is an Ambient Intelligence application for play and therapy that can be adapted to user needs and supports the creative invention of games. PLAYWARE can be used with different physical configurations on the walls and floor. The tiles analyze patients' movements, measuring their progress. PLAYWARE is mainly designed for physical activity and learning through play.

The Soundbeam project has made a positive impact in domains such as disability and special education. Functioning as a musical instrument, it resembles an invisible elastic keyboard suspended in space, enabling the creation of sound and music without the need for physical equipment contact (Ellis, 1995, 2004). Soundbeam finds application in 'sound therapy,' aiming to enhance posture, balance, and cause-and-effect understanding. Additionally, it serves as a platform for creative and experimental pursuits, empowering disabled children and adults to assume roles as composers and performers. (Ellis, 1995, 2004). These technologies offer an enjoyable learning avenue while fostering inclusivity.

Although there is a considerable amount of work being done in the field of technology for neurodiverse people, there is little conversation about the underlying intentions and outcomes. The majority of this work is driven by the desire to help and support but often ends up pursuing a normative agenda of "fixing people," without critical engagement with these implicit agendas. According to Kientz et al., (2013) survey of the field, the focus is often on the physical or functional limitations of autistic people, invoking the medical model of disability. This approach limits design possibilities and raises ethical and moral questions about society's understanding of disability.

When working with autistic research participants, it's crucial to establish a relationship that allows them to play an active role in the design process and contribute their ideas and desires based on their unique understanding of the world (Frauenberger et al., 2018). As designers, we must strive to create positive experiences with technology for autistic children and find ways to assess their impact. By focusing on their strengths such as hyperfocus, creativity, and attention to detail, we can unlock the unique contributions neurodiverse individuals bring to the table. This approach aligns with the neurodiversity movement and offers a more inclusive way to design for all users (Frauenberger et al., 2018).

Children with neurodiverse conditions may need monitoring and support to manage the challenges that come with their condition. Therapy, medication, and other methods are often used to help them, but they can be expensive and not always tailored to their needs (Motti, 2019). Furthermore, interventions that take place in clinics may not be practical for daily life (Fage, 2015).

However, new technologies offer the potential for personalized, context-aware, and just-in-time interventions that can encourage positive behaviours and reduce stress. These technologies offer a less intrusive and more effective way to train individuals for self-regulation. These technologies are versatile and can adapt to meet the needs of a diverse range of users and system requirements. For individuals with neurological differences, integrating technology into their daily lives can help improve their autonomy, self-regulation, self-efficacy, and executive functioning. This inclusive approach can benefit them in education, employment, and independent living (Sonne & Jensen, 2016a, 2016b).

2.5 Tangible interaction

The world of Human-Computer Interaction (HCI) is using the terms "Tangible User Interfaces" (TUIs) and "Tangible Interaction" more and more (Van Den Hoven et al., 2007). This area of study focuses on physical interaction and movement and transforms computer data and resources into tangible objects.

Tangible Interaction (TI) research draws inspiration from various fields like psychology, sociology, engineering, and HCI (Van Den Hoven et al., 2007). With the significance of a multi-sensory approach to learning during the early years, the increasing interest in educational applications of tangible technology is evident. Tangible user interfaces can link digital information to everyday physical objects and environments, thus enhancing the real physical world (Ishii & Ullmer, 1997).

Tangible programming components known as Electronic Blocks can be physically stacked and configured to create computer programs with real-world interactions. Research into Electronic Blocks reveals that young children exhibit a favorable disposition toward utilizing these programmable tangible blocks for circuit and program design. Through interconnecting various blocks, children can guess the behaviour and capabilities of these elements. This study conducted by Wyeth & Wyeth (2001) underscores that children derive enjoyment from the independent exploration and design of such programs, valuing the autonomy they have over the resulting outcomes. Additionally, the children express curiosity about the diverse range of achievable outputs.

Our perception of a product or artifact is influenced by our senses of sight, hearing, taste, smell, and touch. These senses help us understand the value and significance of an object (Kierkels & Van Den Hoven, 2008). According to Vavik et al. (2006) there has been a shift in design for pleasure, inclusive design, and interaction design towards emphasizing the tactile perception of products, rather than just their visual appearance. The sense of touch in particular plays a crucial role in human life as it evokes strong emotional responses. Ackerman (1990) highlights that the primary benefit of touch is its ability to convey feelings of safety and pleasure. While the entire body is receptive to touch, the hands are particularly important for tactile sensations (Prytherch et al., 2002).

2.6 Interactions with LEGO

Various research groups are developing Tangible User Interface (TUI) applications for children by adding electronics to physical toys. TUIs turn these toys into interactive digital devices while retaining their physical properties, allowing for more creativity and imagination in their use. Equipped with sensors, these toys have potential in physical storytelling applications. One such toy is the codable LEGO bricks by MIT Media Labs called the LEGO Mindstorms robot inventor kit, which allows children to build machines, toys and robots and code them to do certain tasks (Tran, 2020). In this research, we use this tool to create a prototype that is further co-designed with the research participants.

With three-dimensional objects like LEGO, children are able to plan ahead and make changes as needed. Connecting LEGO pieces requires precision and coordination, which can help develop and strengthen their fine motor skills (Owens et al., 2008). According to *A short Presentation* (2023) by LEGO Group, the LEGO bricks offer a diverse set of puzzles that require children to associate colours and brick shapes, as well as understand specialized brick arrangements to complete tasks. These activities can stimulate a child's imagination and problem-solving skills as they work towards a goal.

LEGO building toys have been discovered to be an effective tool for autism therapy by a group of researchers. Clinical neuropsychologist Daniel LeGoff is among them, and he started experimenting with LEGO therapy in 2003 (Barakova et al., 2014). His aim was to create a social skills program that could be used in various settings and applied to real-world peer interactions. In 2004, he published a paper showing positive results from the program he developed. Nowadays, there are many practitioners, books, and programs all focused on LEGO therapy (LeGoff, 2004).

2.7 Music with tangibles

Studies indicate that tangible designs are highly effective in captivating young children's interest in early music education, including rhythm, pitch, dynamics, and expression (Ouyang et al., 2020; Geurts, 2014). Tangible interactions foster physical and social interaction among young children, encouraging their imagination and curiosity (Xie et al., 2008).

Researchers have also used curiosity to capture the attention of children and encourage their interest in music. According to Malone (1981), sensory and cognitive elements are the key ingredients for nurturing curiosity. In this study, children were able to learn by using their senses to interact with toys and designs, producing different sounds such as high and low, loud and silent.

When it comes to playful and social experiences involving sound, music is often the go-to platform. Children can learn about sound structures by identifying different instruments in a piece of music and can use their own voices or instrument to contribute to the structure (Turner, 2004). Developing listening skills also involves the ability to separate and combine sounds, as well as locate sounds spatially and associate them with environmental or physical attributes (Fromberg & Bergen, 2015).

3 Methodology

3.1 Defining the theoretical framework

Defining the research's theoretical framework was vital in this research as it formed the intellectual bedrock of how we defined different concepts in this research such as disability or self regulation. It outlines lenses for exploring research questions from the defined framework and offeres a structured understanding of the research design. A well-defined framework enhances clarity by elucidating key concepts and relationships and bolsters research credibility, ensuring logical conclusions.

According to Frauenberger (2015), the experience of disability is complex and shaped by a combination of factors that are both internal and external. These factors include biological differences, personal attitudes, societal stereotypes, economic circumstances, and accessibility challenges. To support this idea, the researcher suggested using critical realism as a philosophical framework for this research, which enables a comprehensive examination of the disabled experience from various viewpoints and at different levels of analysis.

In the world of research, Critical Realism provides a useful structure for thinking about the nature of reality. This includes understanding how different levels of analysis relate to one another, as well as recognizing the impact of various variables and factors. The beauty of this approach is that it acknowledges the strengths and limitations of different research methods, allowing for a more holistic understanding of the research topic. By incorporating quantitative, qualitative, and mixed-methods approaches, researcher could gain a deeper understanding of the complexities of social, historical, and cultural contexts. Ultimately, this theoretical framework encouraged researcher to look beyond surface-level observations and delve into the hidden processes that drive our world.

The needs of children are not just physical, but also relative to history, society, and politics (Tomlinson, 1982, p.75). The development of education systems, technology, and understanding of disability is influenced by powerful economic and political groups in society. These groups direct schools to produce the kind of workers and supporters that benefit their interests (Scott and Scott, 2018). Due to pressure to offer mass education in a cost-effective way, schools often contradict the moral view of education as a public good that aims to meet diverse needs. Ignoring deeper forces such as these leads to blaming individuals under a medical gaze. Inclusion shifts away from this perspective by demanding that traditional society, which is often disabling and oppressive to people with disabilities, must change. A better understanding of disability and inclusion can be achieved by combining the most useful findings and practices from medical and social research into a larger framework called the critical realism stratified ontology.

The study conducted by Frauenberger and colleagues in 2019 sheds light on a new approach to designing technology for children who identify as autistic. Instead of starting with the disability as the central focus, the researchers propose a holistic approach that takes into account the unique needs and perspectives of autistic children. This idea was first introduced by Mankoff and colleagues in 2010, who argued that our understanding of disability shapes the types of technologies that are developed. While a medical model provides practical guidelines for designing technology, it falls short in considering the diverse ways in which technology can be meaningful for people with disabilities.

In essence, critical realism's theoretical framework was a dependable basis for this research design. It provided conceptual clarity, methodological flexibility, depth of analysis, contextual sensitivity, reflexivity, and practical relevance. These advantages bolstered the thoroughness and credibility of research studies, leading to a better comprehension of intricate social phenomena.

3.2 Cooperative enquiry and participatory design

Design approaches such as cooperative enquiry advocate for involving users in the design process to understand their needs and tasks better (Maguire, 2001). Qualitative research methods, such as conducting interviews in a natural setting, aimed to collect individual data points and insights from participants.

In this research study, having a variety of information could provide valuable insights and help pinpoint the appropriate context. Participatory Design (PD) involves viewing the user as more than just a provider of information or assessor of the end-product. Rather, they are an engaged participant who contributes design ideas and makes decisions throughout the design process (Sanders and Stappers 2008). Our aim in this research was to gain insight into the interface and context of a musical tool by involving neurodiverse children and music therapists.

Designing technology with children who have special needs is enhanced by PD, which provides unique benefits. This includes a better understanding of the users and the context in which the technology will be used, resulting in a product that is better suited to its purpose. Additionally, children who participate in PD have increased ownership of the technology they use. PD also offers opportunities for children, including those with special needs, to improve their self-esteem, confidence, and their abilities to collaborate, communicate, and solve problems (Constantin et al., 2019).

The inclusive design community has extensively used and modified PD approaches to cater to the needs of children, especially those with special needs. This research aimed to do the same. In this study, a music interface was used as a foundation for children to explore and reimagine the values associated with this tool.

The cooperative inquiry approach to partnering with children has become a reality, based on the theoretical framework of critical realism. The goal was to find techniques that can support design teams in understanding what neurodivergent children, as technology users, do now, what they might do tomorrow, and what they envision for their future. It's not easy for many adults to understand a child's world, and vice versa. Therefore, a combination of techniques were adapted in this research to form the cooperative inquiry methodology. These techniques did not provide a magic formula for working with children, but rather a philosophy and approach to research that can be used to gather data, develop prototypes, and forge new research directions. The main goal of Cooperative Inquiry is not to study how technology impacts or educates children, but rather to give children the ability to impact technology themselves (Druin 2002).

When designing technology, researchers and designers sometimes involve children as users, testers, and informants. However, Cooperative Inquiry takes a different approach by treating children as design partners (Druin, 2002). In this method, design teams consist of both adults and children, and all ideas are given equal value, regardless of the team member's age.

Unlike other design roles, children are not simply testing prototypes or giving feedback to adults. Instead, design partners are fully involved throughout the entire design process, from generating new ideas to testing prototypes and working with finished products (Druin, 2002; Guha et al., 2008). This is different from other roles that only involve children at specific points in the design cycle.

Cooperative Inquiry involves several practices to aid in the design process. A team of six to eight children aged seven to eleven and an equal number of adults work together as team members for at least one academic year. Both children and adults participate in data gathering, such as note-taking, and prototyping, such as building models, while being immersed in technology in a laboratory setting (Druin, 1999). A key component of successful Cooperative Inquiry is idea elaboration, where adults and children iterate on each other's ideas (Guha et al., 2008). This enables debriefing after a session where all team members can understand how the design ideas have evolved, allowing for true collaboration (Druin & Fast, 2002). While adults bring expertise in areas such as computer science, information studies, and education, children bring their expertise in understanding what it means to be a child (Druin, 2002).

In the field of Participatory Design, techniques refer to activities that aid in completing the design cycle. According to Walsh, Foss, Yip, and Druin (2013), a technique is a creative effort intended to convey design ideas and system requirements to a larger audience. In the case of Cooperative Inquiry, there are various techniques that one can use to make designing with children easier. The following section provides examples of such techniques.

Cooperative Inquiry has a technique called Big Paper (Walsh et al., 2009) that allows a group of three to six design partners to share their ideas using markers or crayons on a large poster-sized sheet of paper. The researcher used this technique with its child research participants on an individual basis. This technique provides a spacious drawing area that enables each design partner to contribute their ideas without having to combine them beforehand. Big Paper is an effective tool for the early stages of the design process as it includes all ideas and generates numerous directions for further work. Even those who have little experience in collaborative work can utilize this technique. It is particularly useful for undefined design problems.

The Stickies technique, as described by Walsh et al. in 2009, involves design partners providing feedback on a working prototype by writing down their ideas on small, adhesive note paper. The notes can include feedback such as like, dislike, design idea, or other relevant categories determined by the design team. Afterwards, the notes are grouped together based on their similarities, which helps to identify areas of the prototype that require further attention for the next iteration. This technique is particularly effective when there is a functional prototype available for evaluation. The researcher combined this technique with Big Paper to review a working prototype with children.

3.3 How to identify and treat data?

Moving away from targeting assumed deficits presents a major challenge when it comes to evaluating outcomes. Traditional assistive technologies are evaluated based on how effectively they support a disabled person in a specific situation. However, with technologies like the ones the researcher has created, it is much more challenging to determine whether they have been successful.

In order to properly assess the experiences of autistic children with technology, it was important to have a framework that can capture those experiences. The concept of experience design (UX) in HCI is heavily influenced by the work of Wright and McCarthy (2008), which suggests that understanding someone's experience with technology requires empathy.

However, this may not be applicable for groups with different life experiences, such as autistic children. To address this, the researcher utilized Actor-Network Theory (ANT) (Czarniawska, 2006) and Critical Discourse Analysis (CDA) (Jäger and Maier, 2009) to examine the relationships between all actors in the network. ANT allows us to consider both human (e.g. the child, parents, researcher) and nonhuman (e.g. smart objects, software) actors, while CDA provides a way to analyze their relationships. Data sources for analysis can range from log data and formal studies to interviews and observations. It's important to note that this understanding of experience is complex and may lead to contradictory results.

A benefit of expanding the definition of experience is that it includes the perspective of individuals who are often overlooked, such as those identified as having disabilities. Although self-reports of experiences have limitations, they provide valuable insight when considered in conjunction with other perspectives. Spiel et al. (2017) advocate for involving autistic children in participatory evaluation as they offer unique insights into the success of an engagement.

Engaging in Participatory Evaluation also provides an opportunity to delve into the core question of which success metrics hold significance (Frauenberger et al., 2018). The research contended that this determination hinges on the intended audience of these metrics. By incorporating children's viewpoints into the evaluation, researcher could thoughtfully contemplate what constitutes success for diverse stakeholders involved. Participatory evaluation proved beneficial in this regard, as it involves a strategic utilization of methodological foundations to customize the process according to the child's perspective and the unique context of co-design (Frauenberger et al., 2018).

3.4 Participation and inclusion

To conduct this study, the researcher invited neurodivergent children between the ages of six and 12, as well as music therapists, to participate. To gain a comprehensive understanding of their motivations and interests, the researcher recruited two children and one therapist for a detailed analysis.

To ensure that only suitable participants were included in the study for neurodivergent children, the researcher used a screening process. The criteria for inclusion required that the children can easily participate in the study, give their consent, and feel comfortable using/arranging LEGO blocks, which is the main interaction in the music interface. Additionally, the children should have been able to self-regulate and participate in two hour-long sessions, during which they can converse with the researcher and share their experiences in the presence of their guardian.

Self-regulation refers to the ability of children to sit through one-hour-long co-design sessions (total two) with their parents present and converse with the researcher to share their experiences. If needed, the children could also use their parents' support to remain comfortable and calm throughout the sessions. The study aimed to accommodate the unique needs and circumstances of each participant, which may vary within the broader neurodiversity spectrum. The researcher was willing to make necessary adjustments to ensure that all participants could try out the interface and enjoy the study to the best of their abilities.

The following inclusion criteria was advertised in posters and through word of mouth/emails for both the selected stakeholders for this research:

3.4.1 Neurodivergent children:

The prospective participant must fall within the age range of six to twelve years. The eligibility criteria included being a clinically diagnosed neurodivergent child between those ages who has the ability to self-regulate and some prior experience using LEGO blocks. The study required the commitment of two in-person, hour-long sessions, during which the child would engage with the interface and share their feedback. Additionally, participants were to be located within the Greater Toronto Area. This focused criteria ensured a consistent and relevant sample group for the study, reflecting the specific needs and interests of the target population.

3.4.2 Music therapists:

The prospective participant was required to have some prior experience working with children. The participation involved two separate, hour-long interview sessions, which could be conducted either in-person or online, providing flexibility to accommodate various schedules and preferences. As the study was open to candidates from anywhere in Canada, this broad geographic scope facilitated a diverse and representative sample of participants, enhancing the richness and applicability of the insights gained.

3.5 Co-design plan

A total of two workshop sessions were planned with each participant as per the following:

Session one: With music therapist

This session was to present the music interface to the therapists and get their feedback regarding the context in which it can facilitate neurodiverse children's well-being. It was to be conducted as a semi-structured interview and later, the participants were to be shown the first prototype of the music interface for their initial feedback on it.

Session two & three: With two neurodivergent children individually

This session with children was to gain initial feedback on the music interface. The time was to be divided between participants trying out the interface and later sharing their experience of using it. Their experience was to be recorded through semi-structured interviews.

Session four and five: With neurodiverse children individually

This session with participants was to gather their review of the reworked design of the interface. The second half of the session was to focus on the effects of using such tools for self-regulation or expression of creativity. This could be recorded through a semi structured interview.

Session 6: To be conducted with music therapist individually

This session was to gather their view of the reworked design of the interface and contextualise learnings from children. It was to be a combination of a workshop and semi-structured interview where learnings from working with children are addressed. All sessions were to be audio recorded, and some important knowledge discussed was to be made note of on paper. All of the events were to be one hour long and conducted at a public place or a location of convenience to the participants. Sessions conducted with therapists could happen online. All the data collected was to be in the form of user experience, pain points and what worked or did not work for the users while using this tool. Thematic analysis was to be used to process this information to answer both research questions.

With the participant's consent, the researcher recorded the entire one-hour session to document every spoken word. Additionally, some photos were taken of the music code that the participants created using LEGO or other materials during the research.

3.6 Data analysis

To analyse co-designs, the researcher transcribed raw data from audio files into readable transcripts. Then, participants' behaviour was classified into themes to gain relevant insights into their viewpoints and interactions following the Actor Network theory and Critical discourse analysis as discussed above. Additionally, drawings and photos were used to directly reflect children's ideas and thoughts on their experiences with the design prototype.

The researcher categorized the collected data into themes based on the theoretical framework that helped to understand children's motivations and engagement with the music interface.

The data collected was based on the participant's personal experience of using the music interface. This information was used to suggest improvements in the design of the musical interface and evaluate its effect on children. To analyse the collected data, the research used thematic analysis, which involved reading through the data and identifying patterns in its meaning to find themes. This approach is an active process of reflexivity where the researcher looks for repeated ideas, topics, or ways of expressing them.

Children were encouraged to use the tool in their own way based on their personal experience with it. The researcher analysed individual data points to make small improvements to the interface but used multiple data points from various participants to identify major themes for significant design ideas associated with the music interface and the context in which it can be used.

3.7 Design of the robot

The design of this tool took birth in a course called experiences and interfaces. The researcher was encouraged to design an interface that used sound as a media in its design. The researcher developed a robot that could respond to colour with sound. This led to colour being sent to the robot, which produced different notes through its colour sensors. The researcher used LEGO Mindstorm's robot inventor kit to design this robot-music-interaction.

Launched in 2020, the latest instalment of Mindstorms series of intelligent remote-control robot kit uses interactive in-apps to design and code these electro-mechanical devices. It uses scratch coding, which is a visual coding environment for children designed by MIT Media Labs to code the interactions of this robot builder kit.

The kit has motors, a colour sensor, a proximity sensor, speakers and a screen to create a wide variety of remote-controlled objects and machines. It also has a main hub in the form of a LEGO brick that controls all these features as its central processing unit in the robot design.

The researcher used this kit to develop a robot that reads different colours of LEGO blocks to produce different notes in music. The robot can read an array of different colours and lengths of LEGO blocks and produce a series of notes that are colour coded.

The speed of the robot, the length of the block and its colour contribute towards the resulting audio output, which is a combination of different pitches of sounds based on musical notes. The robot currently reads five colours i.e. red, blue, green, yellow and black.

The accessible nature of this interface allows the user experiment with creating different tunes without knowing an instrument. (Click here to view a video representation of this robot-music-interaction.)

Figure 1 shows an image of this tool:

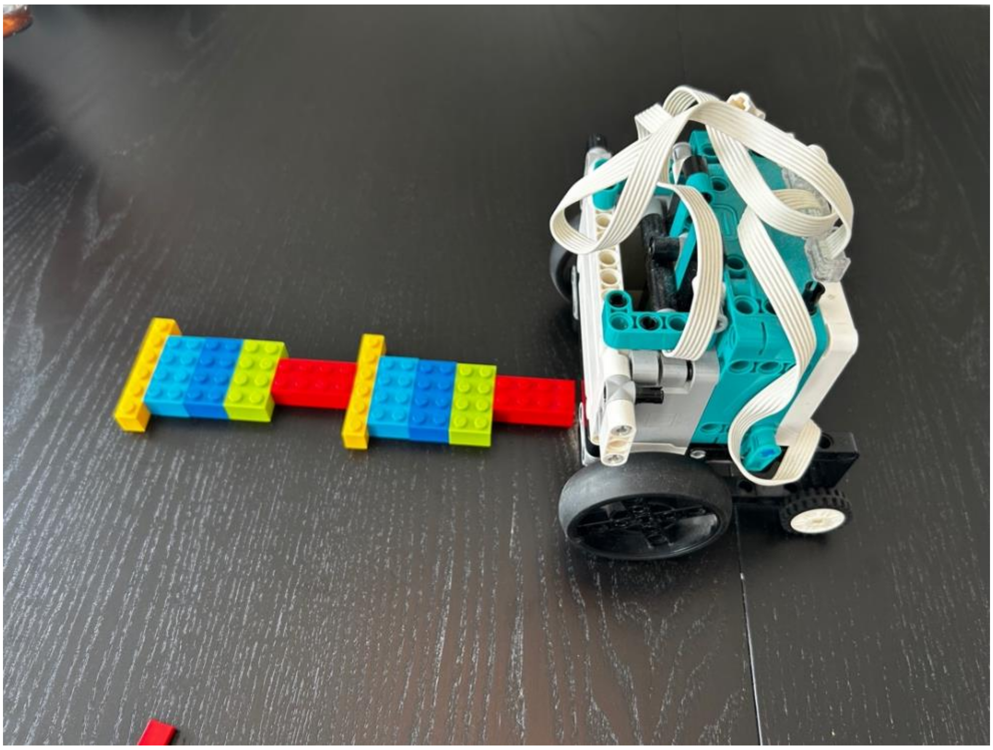

Figure 1 Robot reading the coloured LEGO blocks

The following is the screenshot (figure 2) of the scratch code that was used to code this robot. Each colour corresponds to a note on a piano:

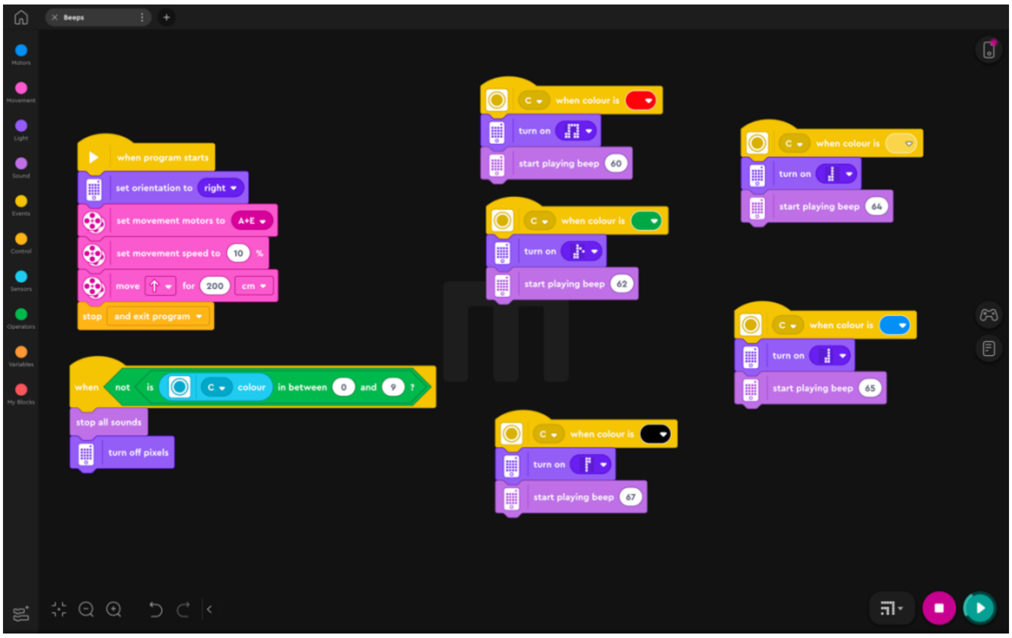

Figure 2 Screenshot of the scratch code used to make this robot

This tool explores the goals and potential benefits of a musical interface that reads colour to produce music, with a specific focus on its application as a tool for creative expression and self-regulation for neurodiverse children. Combining robotics, music, and colour recognition technology, this novel interface serves as an interactive and dynamic learning companion, stimulating curiosity and engagement. The primary goal of the interface is to provide children with a unique and expressive way to create music through colours. By assigning musical notes or sounds to different colours, the interface allows children to experiment, compose, and modify musical pieces by simply interacting with various colours and combinations.

By engaging in co-design alongside neurodiverse children and a music therapist, this study examines the conjecture that investigating the correlation between colours and musical outcomes will enhance critical thinking and logical reasoning abilities in neurodiverse children. Moreover, the research delves into the potential expansion of its applications beyond creative expression and emotional regulation. The research also investigates the musical robotic interface's usefulness in therapeutic contexts, aiding children grappling with emotional or behavioural obstacles. As is paramount with any technology intended for children, meticulous attention is directed towards ensuring safety, user-friendliness, and inclusiveness.

4 Findings

4.1 Ethics and recruitment

An application for research ethics was submitted to Research Ethics Board (REB) at OCAD University on the sixth of April 2023 and after some to and fro of feedback and guidance, a final approval was received on the 16th of June 2023. During the review period, the ethics board received comprehensive feedback on several key aspects of the study. The feedback included clarifications on how researcher defined self-regulation and the obligations of friends and family in finding participants. Details were provided about the in-depth role of music therapists within the study, along with an explanation of how the music tool was being used not merely for prototype testing but as an integral part of a co-design process. The feedback also covered a thorough revision of child consent forms and extended into the engagement of parents, outlining their specific role in the co-design sessions. This multi-faceted feedback reflects a careful consideration of ethical standards and the unique design elements of the study.

After receiving approval from the university's Research Ethics Board, the researcher utilized their social media platforms and created posters to recruit children and music therapists for their study. They also emailed colleagues, friends, and family to generate interest in the research. However, finding participants without a connection or mediator proved challenging. Snowball sampling was found to be a more effective method of reaching out to parents of neurodivergent children and music therapists compared to open calls. It should be noted that social media did result in one child participant being recruited.

Several independent music therapists in Toronto were sent cold emails, inviting them to participate in a research study. However, many of them declined due to their busy schedules. Some also mentioned that they no longer work with children and, therefore, were not a suitable match for the research objectives. Fortunately, music therapists who are part of therapy organisations stepped up and volunteered to connect the researcher with their colleagues who might be a better fit for the inclusion criteria of the study.

To avoid delays in the research timeline, the researcher opted not to use schools or organizations to recruit children for their study. Unfortunately, this also resulted in a limited number of potential participants who met the research criteria. While a Toronto-based organization offered to include a call for participants in their newsletter, the researcher ultimately decided against it due to a lack of REB approval for this method of recruitment. The priority was to adhere to the timeline, and finding alternative recruitment methods was necessary.

Before recruiting participants, the researcher provided reassurance in writing and verbally that they were not obligated to help find other participants or take part in the study. The researcher approached multiple communities to introduce and provide information about the research, to prevent snowball sampling from only one source. This approach reduced the pressure on those approached and avoided any sense of obligation to participate in the study.

After a month-long search for the research participants and considering the challenges in recruiting children who are neurodivergent, the researcher settled with working with two children based in Toronto and Vancouver. Only one child out of these is neurodivergent. This gave the researcher an opportunity to work with children with different abilities and how they interact with the music interface.

The researcher was in touch with 3-4 music therapists but ended up working with only one of them following the research's original plan

4.2 Scheduling co-design and receiving consent

In every communication, potential participants or their guardians were informed about the project through email. The music interface video, along with a brief summary of what the co-design sessions would entail, was shared with the parents of the two selected children and music therapist.

During the summer holidays, many children were on family vacations or were attending recreational summer camps. Parents helped organize co-design sessions with their children and were free to do it at a place of their liking or online as per the child's convenience. The researcher conducted the co-design with the music therapist in person. All sessions were scheduled at the convenience of the research participants.

Before the study began, the children and one of their parents provided consent. The music therapist also gave their consent. Everyone signed consent forms in person or digitally shared them via email. Throughout the study, participants were reminded that they could withdraw at any time, and this information was communicated both in the consent forms and at the start of every co-design session. Participants had the option to withdraw and also had the right to request that their data not be used in the research until it was published.

The participants were informed that any of their identifiable information, including their name, specific location, personal stories or contact information would not be shared in the final report or with anyone outside of the researcher involved in the study. If a participant requested that certain information not be used in the research, their confidentiality would be maintained by arranging for that information to be excluded.

4.3 Synthesizing specific data for co-designs

Throughout the investigation of the robot's interactions with children and a music therapist, various data points were gathered. These inputs proved valuable in understanding the lives of children, the practice of music therapy and the overall perceptions of this type of technology. The children had various thoughts on utilizing the technology. Below are the key takeaways from the co-design sessions utilising actor-network theory and critical discourse analysis to synthesis different data points:

4.3.1 Experience with the interaction

Familiarity with LEGO was significant in creating a sense of comfort for the child participants in their interaction with it. They knew what it looked like, i.e. its shape and form and how different blocks interact with each other. Even when the co-design session took place online, it helped that the participant had played with it before and could understand on some level how the interaction took place.

Prior experience with a musical instrument proved to be helpful for children, as it provided them with a solid foundation to engage effectively with the musical tool. These participants enjoyed the music interface and expressed excitement about the unexpected musical outcomes when placing LEGO blocks together on the machine.

One of them also attempted to create chords by having the robot read two colours simultaneously, which was not possible in the current design of the robot. In one of the trials, they also focused on creating visual patterns rather than considering musical notes.

The child's phrases like *"let's put more green"* inspired the researcher to consider the implications of such language-based interactions and the potential for further improvements.

The colours being coded as per the notes on a piano enhanced the experience for the child in the second co-design session. The number of colours used for the robot's interface was also discussed, with seven or eight colours (representing an octave) being considered suitable. Here, the participant also experimented with various colours and discovered which ones the robot couldn't read and how it affected the music interaction.

Modifications to make the activity more accessible, such as creating graph-like patterns using squares or boxes with colours was suggested to make it easier for the child to draw the patterns.

4.3.2 Material

When the researcher discussed using different materials to create music, paint was a material that was suggested by a child participant in the online co-design, which the research was able to explore with another child due to their availability in Toronto. Paint brushes and paint were used to create patterns, although it was noted that it was a messier process with less control. Something like markers and Lego blocks worked better in this kind of interaction design.

During a drawing session, an accidental spillage of guacamole on the paper led to an exciting discovery. The researcher and child were able to explore a new way in which a user could interact with the robot.

The discussion extended to exploring other stimuli that the robot could utilize to generate sounds. Water-related sounds, such as a flowing stream or dripping water, were suggested, as well as everyday environmental sounds like passing cars. The idea of incorporating paints to create sounds was also considered.

4.3.3 Design of robot's interaction

When asked about their thoughts on the robot design, one of the children expressed contentment with it and did not feel the need to make any changes, emphasizing that they did not want to disrupt its current state. However, at the time of interacting with it, the positioning of the robot and determining its front side proved to be a bit challenging, as it sometimes moved in unexpected directions based on how it was placed.

It was also discovered that certain colours might not be recognized by the robot's sensors due to the marker stroke being too thin or insufficient intensity. The shapes of these strokes and the gaps between two colours on the paper were an important factor into how the robot will read the colour code.

One of the child's parents raised an important question about the necessity of a screen to interact with the music interface. The research clarified that an app on any device, including a phone or iPad, is required for coding the robot, but once programmed, the robot can function independently and is battery charged without the need for continuous screen interaction.

4.3.4 Design ideas

One of the initial ideas that was discussed was how different colours generating different sounds could result in a game for children and a way for them to learn to associate colours with specific sounds. In one of the trials of playing with the interface, the child said *"Let's put more green"* and it inspired the researcher to develop and think about similar interaction styles with the robot. For example, giving literal voice commands to the robot such as the one mentioned earlier or using voice as a medium to create patterns of sounds for the robot to recognise and it produce music out of it.

One of the child participants mentioned that they were skilled at playing the piano and could perform various songs, but they hadn't fully mastered composing music yet. They found it challenging to match words with rhythm and melody. When discussing the concept of music and melody, they described it as a repeated sequence of sounds with variations, highlighting the idea of creating different patterns and repeating them, similarly to Lego patterns. This led to an understanding that the ease of creating patterns with LEGO could possibly be an easy way for kids to foray into the realm of composing music.

The mother's input highlighted the potential educational value of the robot, particularly as a tool for teaching rhythm, beat, and pitch to children in an engaging manner. The suggestion was made to use elements like strips of paper or cloth to create musical patterns and longer versions of sounds to learn about music theory and how music is constructed.

4.3.5 Multimodal music therapy

While there are different ways music therapy is practiced in theory or as per a specific style or approach by a practitioner, the music therapist interviewed for this research suggested that visuals play a crucial role in enhancing the therapeutic experience. They shared that have used pictograms on boards to facilitate communication and choice-making for children during sessions, promoting autonomy while maintaining a structured and predictable environment.

In their practice, the music therapist focuses on helping children with speech, language, and communication difficulties. They select specific instruments to improve breath control, phonation, and speech production. Turn-taking and communication skills are encouraged through collaborative play with larger instruments like the piano. Additionally, they address sensory-motor skills, aiming to enhance the children's confidence and safety in navigating the world.

Regarding the goals of music therapy, the music therapist recognizes the role of self-expression and emotional processing. However, they also emphasize addressing speech production, language skills, communication, and cognitive functions like attention and self-control. By adopting a client-led approach, the therapist aims to create a safe space for meaningful interactions and developments in various aspects of the child's life. This means that they will focus on the immediate needs of the child and their parent and their expectations from a session. Goals can vary based on the needs of the client.

The music therapist also expresses excitement about the potential of multimodal activities and technology in therapy sessions. They believe technology can be a valuable tool, particularly for executive functions and self-expression. However, they caution that each child's specific needs and abilities should be considered when implementing technology-based activities. The therapist finds the musical interface exciting and believes it can engage children differently and aid in executive function and self-expression, especially those who might have difficulty with traditional instruments or are interested in technology. They discuss the benefits of incorporating tangible elements like Legos into therapy to move away from excessive screen time.

5 Discussions

Within the primary objective of this research report, we embarked upon an essential exploration that focused on the utilization of a music robot as an interactive instrument tailored for the engagement of neurodiverse children. To achieve this aim, a partnership with a music therapist was also forged, thereby augmenting the therapeutic dimensions of this initiative. However, serendipitous circumstances intervened, presenting an unforeseen juncture that substantially enriched the scope of our investigative endeavours. This fortuitous turn of events facilitated the inclusion of children spanning a spectrum of abilities, thus heralding a comprehensive and diversified perspective concerning the effectiveness of the music interface.

The choice to incorporate both neurodivgent and neurotypical children within this study was a deliberate decision underpinned by a steadfast commitment to inclusivity. This strategic convergence of multifaceted viewpoints aspired to transcend conventional demarcations and reshape our comprehension of interactive design for children. The collaborative design sessions served to illuminate the trajectory towards an inclusive future. Through these meticulous co-design sessions, a resounding narrative emerged—one that transcended disparities in cognitive profiles.

The researcher's close observations during the co-design sessions shed light on various aspects of the music robot's effectiveness using the Actor Network Theory and Critical Discourse Analysis. The sessions and research results provided valuable insights into the feasibility and efficacy of the music robot in engaging children and supporting their emotional expression, self-regulation, and relaxation. The research analysed different aspects of the interface and the interaction and the relationship between them to critically view the usefulness and impact of the Robotic-Music-interface. The insights from the co-design led to valuable design implications for optimizing the user experience. For instance, incorporating different materials other than LEGO blocks into the interface catered to the unique sensory needs and preferences of certain participants, enhancing their engagement with the music-making process and the relationship between all these factors.

This section presents an in-depth discussion of the various facets touched upon during the design of the music interface, its applications in different contexts, and its impact on children's self-expression, self-regulation, and relaxation. The discussion draws insights from the co-design sessions, observations, and the researcher's review of the existing literature throughout the study.

5.1 Robotic Technologies for Emotional Regulation

The music interface had a profound effect on children in all the sessions conducted with them. Its joyful nature and play with the robot and the patterns created out of LEGO, resulting in music led to a very fulfilling experience for them.

The use of robots and technology in supporting emotional regulation for neurodiverse children has gained attention in recent years. Studies have explored the use of AI robotic toys and physical environments to build children's emotional capital and enhance their social-emotional literacies (Kewalramani et al., 2021). Robots with diverse appearances and behaviours have been found to elicit different perceptions and responses from children, highlighting the importance of designing robots that cater to individual needs and preferences (Cheng et al., 2017).

These interactive and dynamic playmates not only entertain but also contribute to children's development in various ways. Robotic technologies offer socio-emotional tools and multimodal resources in childhood settings, mainly serving children with diverse needs. While it cannot replace caregivers and educators, integration of technologies can be combined with non-technological interventions to assist in the child's social-emotional interests and imagination. (Kewalramani., 2021).

The development of emotional regulation robots for neurodiverse children holds great potential in supporting their social and emotional well-being. Neurodiverse children, including those with ASD, often face challenges in emotional regulation and communication (Solomon et al., 2011). Research has shown that these children may have higher levels of internalizing symptoms, such as depression and anxiety (Solomon et al., 2011). Therefore, interventions that target emotional regulation can benefit their overall development.

Designing technology for and with neurodiverse children, including those with ASD, has been a focus of research in the field of Human-Computer Interaction (HCI) (Sobel et al., 2015). Technologies that promote empathy, friendship development, and social and emotional intelligence have been developed and tested to facilitate inclusive play and learning experiences for neurodiverse children (Sobel et al., 2015).

5.2 Use of LEGO blocks and robot developer kit

In the context of this research, the remarkable recognizability of LEGO played a pivotal role in captivating children's attention and fostering a sense of comfort with the interface and materials. This made the overall experience more accessible and enjoyable for the young participants. This recognizability was a crucial catalyst in initiating engagement and active participation among the children.

The versatility and user-friendly nature of LEGO proved to be instrumental in shaping a coherent narrative for the children, one that was easily comprehensible and intuitive to work with. The inherent flexibility of LEGO components allowed the children to express their creativity and ideas with ease, facilitating a smooth and enjoyable interactive experience.

Moreover, LEGO's distinctive additional benefits, synergistically influenced the success of the research design. Research has demonstrated that engaging in activities with LEGO blocks can enhance cognitive skills, spatial reasoning, problem-solving abilities, and creativity (Malide et al., 2012). These benefits are particularly relevant for neurodiverse children, including those with Autism Spectrum Disorder (ASD), who may have unique learning styles and preferences.

The visual nature of LEGO blocks and the ability to create patterns using different colors can be particularly appealing and engaging for neurodiverse children. Visual patterns provide a structured and organized way for children to explore and understand their environment. The use of LEGO blocks allows children to manipulate and arrange the blocks in different patterns, promoting fine motor skills and hand-eye coordination (Malide et al., 2012). Building and creating with LEGO blocks can encourage collaboration, turn-taking, and communication with peers and caregivers. The process of working together to create visual patterns fosters social interaction and cooperation (Malide et al., 2012).

It is important to note that the benefits of using LEGO blocks and their colours for neurodiverse children extend beyond the immediate engagement and play. The skills and abilities developed through these activities can have long-lasting effects on their overall development and well-being. The cognitive, social, and sensory benefits of engaging with LEGO blocks can support neurodiverse children in various contexts, including educational settings and daily life activities.

The inclusion of the premade robot is not indicative of a mere product testing endeavour, but rather serves as a catalyst for participatory design—an approach that aligns intricately with the research objectives, particularly when working with neurodiverse children.

Traditional product testing typically involves subjecting a product to rigorous assessments and evaluations, often driven by predetermined criteria and benchmarks. This approach, while valuable in many contexts, can fall short when applied to projects involving neurodiverse children. Neurodiversity encompasses a spectrum of cognitive, sensory, and behavioural differences, which can render conventional product testing methodologies insufficient for capturing the nuanced needs, preferences, and interactions of this diverse population.

In contrast, our utilization of the predesigned robot is deeply rooted in the principles of participatory design. Participatory design involves collaborative engagement with end-users—neurodiverse children, in this case—right from the inception stages of a project. This approach places these children at the center of the design process, allowing them to actively contribute insights, preferences, and feedback. By involving neurodiverse children as co-designers, we transcend the traditional boundaries of product testing and unlock a wealth of experiential knowledge that is essential for crafting solutions that resonate deeply with their unique requirements. This process extends beyond a surface-level evaluation of a product's functionality and delves into the realm of co-creation, wherein the participants become partners in innovation.

5.3 Alternate ways of creating music

In addition to its primary function as a playful tool, the designed interface also serves as an alternative means of creating music. Based on discussions with the music therapist, the potential of this tool as a valuable asset in different contexts such as therapy and education, becomes evident. The therapist's insights suggest that this musical tool can create a welcoming and enjoyable experience for children of diverse abilities. The interactivity and novelty of this tool impact the arousal, mood, and attention of a user.

Moreover, interactive and novel music and sound creation methods suggested by the music therapist and others mentioned in the literature review have been found to be effective in promoting social interaction and communication skills in neurodivergent children. The participating music therapist also confirmed the advantages of improvisational music creation where children can explore different instruments in their own way to use different media to produce musical sounds. Studies on improvisational music therapy have also shown that engaging in musical interactions can lead to increased emotional responsiveness, initiation of engagement, and joy in children with autism (Wigram et al., 2009).

While individual reactions may vary, the interface's design allows for simplification, making it accessible to a wide range of users. Integration of different coloured electronic blocks, rather than a singular robot entity, can yield an array of music outputs characterized by comparable interactivity. This novel approach opens avenues for exploration where color-coded electronic blocks, when combined, generate distinctive musical responses. Furthermore, the utilization of a mobile phone application equipped with colour pattern recognition capabilities amplifies the accessibility of this tool, rendering it available to a broad spectrum of users. This democratization of access stands in contrast to the potential financial barriers associated with procuring an elaborate robot system.

Furthermore the integration of a mobile phone application extends the reach of this tool beyond traditional hardware limitations. Leveraging the smartphone's camera to interpret colour patterns transforms the ubiquity of these devices into instruments of creativity and engagement. This democratization of access aligns with inclusivity, as it provides an avenue for children from varied backgrounds to engage with the music-making process, irrespective of their technological resources. Furthermore, the possibility of developing different levels of this interactive tool caters to various audiences, accommodating their unique preferences and needs.

The tactile, auditory, and visual stimulation involved in creating musical output with LEGO blocks or other media used in the co-design sessions can help children with sensory processing differences to regulate their sensory experiences and improve their sensory integration skills (Wigram, 2006). This can further contribute to their overall sensory development and enhance their ability to engage with their environment. Children can explore different sounds, rhythms, and melodies, allowing them to express their emotions and experiences in a non-verbal and abstract way (Wigram, 2006).

5.4 Creating patterns for self-regulation

Neurodiverse children manifest a spectrum of self-regulation methods, drawing upon their distinct strengths while navigating individualized challenges. Our study's participants divulged a range of strategies they employ for relaxation and self-regulation. These approaches encompassed various activities such as indulging in beloved television shows, engaging in games, seeking solitude, or even involving themselves in culinary endeavours. Within the specific context of our conducted activity, participants exhibited a genuine appreciation for the concept of crafting music in a similar manner.

One of the common strategies neurodivergent children employ involves engaging in repetitive behaviours, something one of the parents' mentioned as their general understanding in the co-design session. In this context, a music interface utilising LEGO blocks to facilitate pattern creation, with music output as a rewarding outcome, proves to be a beneficial tool. Repetitive behaviours are prevalent in autism spectrum disorder (ASD), yet evidence-based interventions targeting these behaviours remain limited (Boyd et al., 2011). Nonetheless, interventions focused on addressing lower-level repetitive behaviours have shown promising results (Boyd et al., 2011). Through the process of crafting musical patterns with LEGO blocks, neurodiverse children can experience a heightened sense of comfort and predictability, potentially aiding their self-regulatory efforts.

Moreover, delving into the understanding of pattern creation as an integral aspect of this music tool presents an intriguing direction for further research. Child Participant One was very intrigued by just creating different patterns with colour LEGO blocks without having to think about the musical output. By exploring how neurodiverse children approach pattern construction and their preferences in designing musical sequences, this research can gain valuable insights into the effectiveness and appeal of the tool. Such investigations could lead to valuable refinements of the interface, ensuring its optimal suitability and usability for this specific user group.

Additionally, the neurodiversity paradigm emphasizes creating contexts in which neurodivergent individuals can thrive (Hamilton & Petty, 2023). This approach recognizes the unique strengths and challenges associated with neurodiversity and aims to provide supportive environments that accommodate individual differences. By fostering inclusive and accepting environments, neurodiverse children can feel more comfortable and regulated.

Through two sessions with child Participant One, we observed their spontaneous engagement with the tool. However, insights from the music therapist highlighted that the tool's suitability may vary among children, with some preferring a simplified and more planned approach to its utilization. Thus, it is important to note that self-regulation strategies may vary among neurodiverse children, as each individual has their own unique needs and preferences. Some children may benefit from sensory-based strategies, such as using sensory tools or engaging in sensory activities, to regulate their sensory experiences (Mazurek et al., 2012). Others may find comfort in routines and predictability, relying on structured schedules and visual supports to manage their daily activities (Macdonald et al., 2021).

5.5 Augmented music therapy

The impact of multimodal, creative music therapy techniques on neurodiverse children has been extensively studied, and the findings highlight several positive outcomes. The participating music therapist confirms that parents of neurodiverse children often use music therapy to aid them in regulating their communication skills, attention and sometimes to have some respite from their day-to-day life. The agenda within a session with their client is often flexible, where the client decides what and how they're going to go about the session, playing the instrument they want to and how they want to play it.

The researcher understands that using this music tool as a means of doing therapy in a clinical setting can lead to many benefits for children. Kim et al. (2008), an investigation of the effects of improvisational music among autistic children, confirmed the effective facilitation of joint attention behaviours and non-verbal social communication skills than play sessions with toys (Kim et al., 2008). Wigram et al., (2009) explored the social-motivational aspects of musical interaction in improvisational music therapy for children with autism. The results showed significant evidence supporting the value of music therapy in promoting social, emotional, and motivational development in these children (Wigram et al., 2009). The analysis of children's overall experiences with this tool and insights from the music therapist regarding its applicability for improvisational music creation indicate that it holds potential as a valuable resource for children's therapy, offering both therapeutic benefits and an enjoyable experience.

In addition, McDermott et al. (2018) explored indirect music therapy practice and skill-sharing in dementia care. The study highlighted the potential benefits of music therapy for people living with dementia and emphasized the importance of the way caregivers approach and interact with them (McDermott et al., 2018). The researcher aims to take this music interface to Dementia care centres as a recreation activity. Moreover, exploring the long-term effects of the music robot in sustained music therapy sessions is an exciting avenue for future investigation. Investigating the robot's applications across different age groups and therapeutic contexts may further expand its potential as a therapeutic tool.

The study's results and observations highlight the potential applications of the music robot in music therapy settings. Its adaptability to accommodate individual needs and preferences positions it as a promising tool to support music therapists in their sessions with neurodiverse children. The robot's ability to engage and facilitate expressive and regulating experiences opens new avenues for augmenting therapeutic practices and promoting positive outcomes in music therapy interventions.

5.6 Co-design experience

This research report utilized a participatory design methodology to engage children in the co-design process. The findings highlight the importance of involving children as active participants and co-designers, recognizing their unique perspectives, creativity, and expertise.

It also acknowledges the challenges and considerations in implementing co-design, including the need for age-appropriate methods, understanding children's developmental abilities and the kind of questions they have the expertise to answer. This can be tackled by simplifying the questions in the form of a game and indirectly reaching a response.

Overall, this research report contributes to the growing body of knowledge on co-design with children and highlights the value of their active involvement in shaping the design of products, services, and experiences.

5.7 Contextualising future possibilities

The future of multi-sensory learning tools tailored for neurodiverse children holds great promise, as these tools have demonstrated significant benefits in catering to their unique needs and fostering their holistic development. Wigham et al.'s (2014) research sheds light on the intricate interplay between sensory processing abnormalities, anxiety, and restricted and repetitive behaviors (RRBs) observed in individuals with autism spectrum disorder (ASD). A deeper comprehension of these relationships serves as a foundation for designing targeted interventions that address sensory processing difficulties and associated challenges effectively.

Furthermore, it is crucial to consider the broader social model of neurodiversity when conducting research and developing tools for this community. This model emphasizes perceiving individuals within their complete humanity, recognizing and celebrating their differences rather than focusing solely on perceived deficits, as advocated by the traditional medical model (Milton, 2012; Kapp et al., 2013). Embracing the social model encourages an inclusive perspective that respects and values neurodivergent identities, fostering a more equitable and empathetic approach towards understanding and supporting individuals with diverse cognitive abilities.

The concept of the "double empathy problem," as proposed by Milton (2012), reinforces the significance of relationality and interaction in comprehending autism. This notion underscores the importance of acknowledging both neurodivergent and neurotypical individuals' perspectives and experiences to facilitate effective communication and mutual understanding. By adopting this perspective, research and development efforts can be grounded in a collaborative and inclusive ethos, promoting authentic engagement and meaningful connections between neurodiverse children and their peers and caregivers.

Overall, study's findings emphasize the importance of inclusive design in creating interactive tools that cater to diverse abilities and foster meaningful therapeutic experiences. The music interface's potential applications in music therapy settings open new horizons for research and innovation in the field, making it a promising tool to enhance therapeutic interventions and support positive outcomes for neurodiverse children. As this research paves the way for future investigations, it also serves as a reminder of the boundless possibilities that technology holds in enriching the lives of individuals with unique abilities.

6 Limitations

While the co-design of this music interface with children with diverse abilities and music therapist has yielded reassuring results, this section will candidly discuss the limitations faced during the research. By openly acknowledging these constraints, the researcher strive to foster a culture of continuous improvement and encourage future researchers to build upon this work to create even more sophisticated and impactful musical interventions for creative and regulatory applications.

Undoubtedly, the co-design approach offered numerous advantages, promoting user-centeredness and fostering learning through collaboration. Due to the unconventionality of this research approach, there is a paucity of established evaluation frameworks specifically tailored to assess co-designed musical interfaces for children. Following are some of the limitations discussed in detail:

6.1 Recruitment as an international student

Recruiting research participants as international student in a new country comes with distinct challenges and opportunities. Not having a solid network within the new academic community and away from familiar surroundings and contacts, the researcher found it difficult to identify potential participants for their research. Navigating an unfamiliar academic and cultural setting, the task of gathering participants, especially neurodiverse children, posed significant challenges, given the caregivers' heightened concern for a vulnerable part of society. The researcher discovered that having a mediator or collaborating with an established organisation could have been beneficial in this regard.

6.2 Small sample size

A significant limitation of this research report is the small sample size of neurodiverse participants. Due to the limited number of individuals with neurodiverse conditions who participated in the study, the findings may not fully represent the diversity and complexity of the neurodivergent children's experiences. The small sample size could restrict the generalizability of the results and limit the ability to draw robust conclusions about the broader neurodiverse community.

A small sample size may not fully capture the diversity and complexity of the target population, leading to skewed findings that don't represent the broader range of experiences. Qualitative research aims to understand specific contexts deeply, but a small sample can hinder extending findings beyond immediate participants, limiting external validity. Limited representation may impede detecting emerging patterns or themes. A small sample might overlook nuances in participants' experiences due to restricted data points.

Qualitative research often delves deeply into exploration, but statistical data contributes context within a broader population. By supplying quantitative context, statistical outcomes heighten the generalizability of qualitative insights. This permits researchers to offer more informed statements about the prevalence, distribution, or patterns of certain themes or behaviours. Merging qualitative and quantitative data bolsters the validity and reliability of research conclusions. Statistical outcomes can confirm or enhance qualitative findings, fostering a more holistic understanding of the studied phenomenon.

Quantitative data can furnish quantitative context for qualitative findings. For instance, if a qualitative study uncovers a particular trend or theme, statistical data can detail the frequency or prevalence of that trend within a larger populace. While qualitative research strives to unveil patterns and narratives, statistical analysis goes a step further to identify and quantify these patterns. Statistical methods can spotlight significant relationships or correlations that might be challenging to discern solely from qualitative data.

Therefore, while the study provides valuable insights into the experiences of the participants involved, caution should be exercised in extending these findings to the broader neurodiverse population. Future research with larger and more diverse samples is essential to validate and build upon the findings of this study.

6.3 Missing stakeholder

By not directly involving musicians in the research process, potential nuances and specific requirements that are essential for creating intuitive and artistically expressive music tools may have been overlooked. Musicians possess a deep understanding of their craft, and their input could have shed light on critical aspects such as preferred workflows, stylistic considerations, and real-world challenges faced during the composition process or using an instrument. Interviewing musicians would have allowed the research to incorporate their expertise and practical knowledge into the design and functionality of this tool.

Furthermore, by engaging musicians in interviews, the research could have explored potential areas for innovation and discovered novel ideas that may not have been evident from a purely technical or theoretical standpoint. The insights gained from these interviews could have sparked new avenues of research and facilitated a deeper understanding of the interplay between technology and musical creativity for children.

6.4 Relationship with technology

A notable limitation of this research is the lack of in-depth exploration into the relationship between the children research participants and their day-to-day use of technology. While the study provides valuable insights into certain aspects of the children's interaction with technology, a more comprehensive investigation into their daily technology usage patterns and habits could have yielded a deeper understanding of their digital experiences.

By delving deeper into the children's day-to-day technology practices, the research could have uncovered potential variations in usage across different devices, applications, or platforms and how that could have been replaced with a tool such as this. This additional granularity would have provided a more nuanced view of how technology integrates into their lives, allowing for a more comprehensive analysis of the impact of the music interaction on various aspects of their development, behaviour, and well-being.

7 Conclusion

The research embarked on an exploration of a music reading and writing interface tailored to the needs of neurodiverse children, with the goal of providing them a platform to unleash their creativity and foster self-regulation. Various multisensory aspects of the music interface were thoroughly investigated to uncover potential benefits for this specific user group.

The development of emotional regulation robots for neurodiverse children, especially those with autism spectrum disorder (ASD), presents a promising avenue for enhancing their social and emotional well-being. By integrating robots and technology into interventions, researchers and practitioners can offer personalized and engaging experiences that cater to the unique requirements of neurodiverse children. However, further research is essential to examine the long-term effects and efficacy of such interventions, while prioritizing ethical considerations and inclusivity in the design and implementation of these technologies.

The active involvement of children with diverse needs and music therapists as co-designers in this research enriched the process and yielded valuable insights into the music interface's potential. Identifying ways to enhance interaction and incorporate diverse materials as inputs to the music interface for generating audio outputs emerged as crucial improvements. The research also highlighted the versatility of the interface, adaptable to various contexts and services, benefiting children with different needs and age groups, and even extending to different demographics, such as elderly individuals in dementia care units.

Furthermore, McDermott et al. (2018) delved into the realm of indirect music therapy practice and skill-sharing within the context of dementia care. The study shed light on the potential advantages that music therapy holds for individuals living with dementia, underscoring the significance of caregivers' approaches and interactions with them (McDermott et al., 2018). Building upon this, the researcher aimed to introduce this musical interface into dementia care centers as a recreational activity.

The exploration of the enduring effects of the music robot through extended music therapy sessions presented an intriguing path for future investigations. The prospect of examining the robot's applications across diverse age groups and therapeutic settings had the potential to broaden its scope as a therapeutic instrument.

Further research is necessary to explore specific mechanisms and strategies that optimize the use of LEGO blocks for different neurodiverse populations. Understanding how pattern-making with LEGO blocks can be harnessed to receive audio as output opens up intriguing possibilities for advancing the interface's functionality and appeal.

Engaging in music and sound creation activities provides a safe and expressive outlet for neurodivergent children to process and regulate their emotions. This conclusion underscores the potential benefits of interactive and novel methods of music creation for neurodivergent children, advocating for their integration into therapeutic interventions and educational settings. Such endeavors offer valuable opportunities for growth, development, and self-discovery for these children.

The research's analysis highlighted the propensity of neurodiverse children to engage in pattern creation, aligning with previous findings suggesting the benefits of low-level repetitive tasks for providing a sense of structure and control. This understanding paves the way for further refining pattern-making within the music interface to receive audio as an output.

The research design and co-design process with participants have revealed valuable insights into tailoring the music tool to the specific needs of the neurodiverse population. Expanding collaborations with musicians and a more diverse demographic of neurodiverse children, with a larger sample size, will undoubtedly contribute to the ongoing refinement and improvement of this valuable tool.

In conclusion, this research emphasizes the importance of innovative and interactive approaches to music creation for neurodiverse children. By providing a nurturing and empowering environment, these tools have the potential to enhance their well-being and creative expression, unlocking new possibilities for their personal growth and development. As further investigations unfold, the transformative impact of these music interfaces on the lives of neurodiverse children becomes increasingly evident, offering optimism for a more inclusive and supportive future.

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9 Appendix A: Case Studies

The accounts below are the raw data points collected to be able to paint a rich and detailed picture of our collaborations with the children and the music therapist. These semi-structured interviews give us an in-depth insight into the perspectives of our participants. All sessions were audio recorded. Additional data was collected in the form of photographs taken by researcher and children, and actual artifacts created in the workshop sessions. Since each co-design was very different in nature and content, it is valuable to document the important details of each of these sessions one by one. The following are direct observations of each co-design session that took place with our co-designers followed by its synthesis using actor network theory and critical discourse analysis:

9.1 First Co-design With Child Participant One:

This section describes the co-design that took place at child Participant One's home who is neurotypical. They are ten years old. During the researcher's visit to their home in Toronto, the researcher found out that the homely environment was comfortable for the participant. As the research participant had previously seen a video of this robot interaction, their first question was whether they could appear on the box of the robot kit once its final design was ready and it was all set to hit the market. The child was engaged and attentive as they learned about the robot's design, showing a positive attitude towards technology in use that includes a colour sensor, motors, and a speaker. After a brief introduction, the child was encouraged to interact with the music interface where they tried using their piano playing skills to put together different colours creating a combination of music notes.

One concern raised by the parent was whether the child would always require a laptop or screen to use the robot. The researcher explained that while an app on a device is needed to code the robot, a phone or iPad could also be used to code the interface. Additionally, it was noted that a phone or screen may not be necessary once the robot is designed, as the code can be saved within the machine

During the session, the researcher and child participant discussed the possibility of creating a game, such as 'Guess the color,' which would involve identifying a colour based on the sound it produces. After several attempts at using the interface, the child discovered colours that the robot did not recognize and how it affected the music interaction. They also created a rainbow pattern for the robot to read which resulted in an audio output.

To better understand the child's motivation for learning an instrument, the researcher inquired about their piano playing. The child revealed that they had been learning for two years after being inspired by their aunt's playing. They also shared that while they can play music by looking at a book, they had not yet learnt to compose. They said they found it challenging to think of words to go with the rhythm and beat. However, they enjoy writing poems in general.

During the research, the child was asked about their definition of music and what would make a sound melodious according to them. The child responded that music is a sound that gets repeated and melody is the repetition of a pattern, which is similar to creating patterns with LEGO blocks

In addition, the child shared their favourite sounds which included the voice of their favourite YouTuber and their cat's purring. The child also expressed their appreciation for the music interface, saying that it was interesting how the machine could turn any sound into music.

During the study, the child attempted to create a chord by having the robot read two colours simultaneously. However, the robot was unable to perform this task due to its current design. The child also suggested using paper cut-outs instead of LEGO blocks or a coloured floor for input and discussed the robot's capability of moving over it, sensing the colours and producing sound.

They shared their thoughts on the music interface:

> *"I like how you can put something like this. You don't expect it to be music. And then when you put the machine over the top, it's just, like, da-da-da. And it's, like, music."*

Figure 3 shows the last colour code pattern that the child created with LEGO blocks:

Figure 3 A series of musical-colour code made of LEGO blocks

9.2 Co-design Two With Child Participant Two:

This session was conducted online with a neurodiverse child participant even though initially, the criteria was to do it in person with the child participant. Due to the non-availability of participants, especially in the case of children, the researcher decided to work with this participant online. The child Participant Two, aged ten years is based in Vancouver and joined the meeting with their mother.

During the session, it was discovered that the child participant in the study had a strong interest in science, particularly in conducting experiments. This passion for science proved to be beneficial in facilitating the research, as it enabled a better understanding of the components involved in the project. The child's enthusiasm for exploration and creativity was evident, and they expressed delight in the flexibility of the project, believing they could create anything they desired, using readily available materials found at home apart from LEGO.

The researcher also discussed the nature of sound the child likes to listen to in their environment to which they said they liked to listen to birds and the sound of their dad cooking. The child also shared that they were not yet taught how to compose music as their music learning exercises primarily focused on playing pre-existing songs.

The participant was asked how they would talk about robot interaction to their friends. To depict that, the researcher asked them to design an advertisement that talked about the benefits of the robot to their friends. Later the child discussed the details of the contents of the advertisement as seen in figure 4.

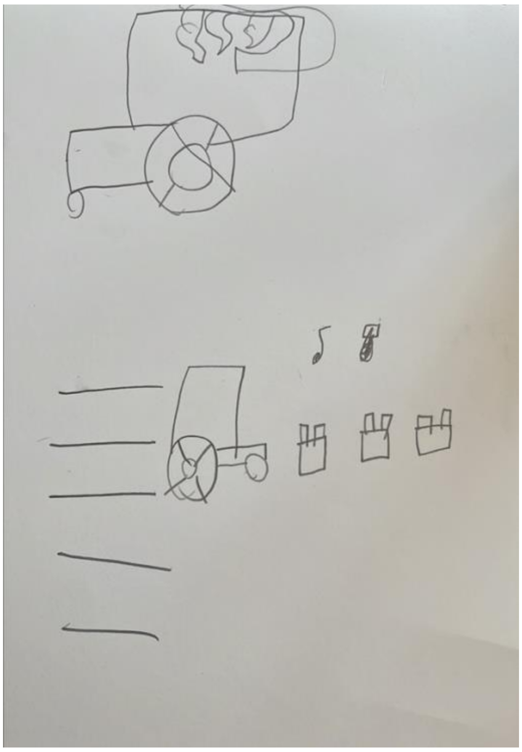

Figure 4 A series of musical-colour code made of LEGO blocks

The child really enjoyed the robot as it was, and when asked if they would like to change something about it, they mentioned that they think it was already good and they didn't want to mess it up. The researcher also encouraged the child to think of what other materials they would like the robot to read instead of LEGO blocks and their answer was "*paint*."

During our discussion, the researcher and participant realized that using paint as a stimulus was a useful idea and could lead to some very interesting interactions. Other ways in which the robot could generate sounds were also explored, such as using sound as input to create different types of sounds. It's proximity to systems like Alexa[1] was brainstormed and different ways to simplify its creation and make it produce musical sounds more easily.

The co-designers discussed the sound of water flowing like a stream or cars driving by and other everyday sounds that could be used as input for the robot to come up with interesting melodies. If a robot is designed to listen to the sound of water like a stream, what kind of output should it produce? What sound should the robot make and how should it process it? These were some of the interesting questions that were discussed with the participant. They did not have prompt answers for everything but it made them think about the possibilities within this kind of interaction design.

The mother suggested that this could be an interactive tool to teach kids about rhythm, beat and different components of music in a creative way. She said it could be designed as different proportions of musical patterns on cloth or paper to teach about music theory and how music is structured.

During the session, the child revealed their preferred activities for relaxation. They mentioned enjoying creating things, going out to play with friends, or simply spending time alone in their room watching TV or playing video games. This provided the researcher with valuable insight into the various methods the participant used to self-regulate, which included both high and low energy activities.

9.3 Third Co-design With Child Participant One:

In this session that took place in Toronto, inspired by the previous co-design with child Participant two, the researcher supplied child Participant One with markers and paints instead of Lego blocks to write musical code.

One of the things that came up in this session was that the participant found it difficult to identify the front side of the robot. This was important for them to ensure they positioned the

[1] Alexa by Amazon is a virtual assistant proficient in natural language tasks like voice interaction, music playback, to-do lists, alarms, and delivering real-time news. It serves as a home automation hub, controlling multiple smart devices (Wikipedia contributors, 2023).

robot correctly in front of the colour pattern. It would often move in a different direction as the correct side of the robot was unknown.

The researcher and the participant also found out that if the robot doesn't read a certain colour, it may be because the thickness of the marker stroke was not enough for the sensor to capture the colour. Or sometimes the colour wasn't a perfect red or green or blue for the robot's sensor to read it correctly. This suggests that it was easier for the robot to sense LEGO colour blocks for its perfect shape and form. In the usage of markers and paints, the participant also found out the kind of gap that should be there between two colours on paper.

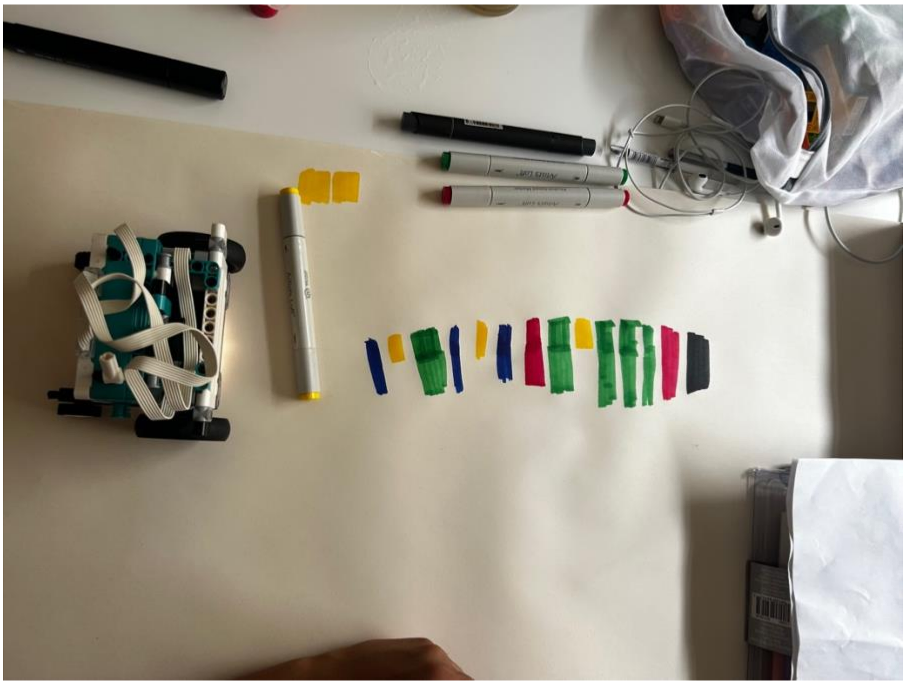

Figure 5 A series of colour code made with markers on paper

Since the child's marker strokes were uneven and unparallel, they elongated these lines to try to fix them, as shown in Figure 5. The child also faced problems with drawing straight lines in comparison to working with LEGOs, where the blocks came together in a straight line ensuring the Robot did not miss a colour. A ruler was offered to the participant which they decided not to use because they wanted to freely play around and draw on the sheet of paper.

The researcher noticed that the child was more interested in creating visual patterns with the markers than think of notes or putting together colours which might end up as musical. They said, *“I'm not going to think about the notes.*

I'm just going to make a colour pattern.”

They added that they haven't memorised the colour code corresponding to different notes yet so they didn’t know what colour represented what note. They wanted to not think about what the pattern would sound like.

The child was excited about creating a new pattern and curious about what they would name it but decided to play it first to see if it spoke to them.

The child participant also explored long and short patterns and different thicknesses of marker stroke that would lead to varied lengths a note will be played. They named one of their music patterns as ‘The Wiggles.’

Since in this session, the researcher was able to code the colours as per the notes of a piano, in some patterns created by the child the output sounded musical. The co-designers also discussed the ideal number of colours that the robot should read which the child suggested should be 8 or 7 to cover a full octave in a piano. The child also suggested that hues and tints of the current 5 participating colours could also potentially participate in the interaction.

The parent suggested that often kids have a tendency to make patterns. Like putting similar things together or drawing them. Such as similar vehicles, objects or chips in an aisle. According to them, children want to organize these elements into size, colour or brand.

The participant also used paintbrushes and paint to create these patterns. The researcher found out that for children it is difficult to maintain the coherence of the pattern in terms of colour thickness. The paint turned out to be not as good as markers or LEGO blocks to create patterns within this interaction.

The child dropped some guacamole on the sheet of paper while drawing, and it resulted in an idea where food could be used for its colour as input instead of paint or LEGO blocks.

The co-designers also discussed creating a graph-like pattern for the child participant to draw the patterns on with colours and they agreed it was a good idea and they would be happy to work with it

Since playing chords is an important function in music, it was suggested by the child to add the possibility of reading two colours simultaneously in the next iteration of the robot.

The child was encouraged to draw an advertisement to show their friends what the robot did and how they would discuss the benefits of this robot with their friends. Their drawing is shown in figure 6. They named it ‘The Bot’ and used different colours to draw it with symbols of music on it.

Figure 6 An advertisement of the LEGO robot created by a child participant

Here’s how the child thought they would tell their friend about the robot.

> *“Sally (name changed), there's this really cool new toy out. So basically, it's like a robot and then you make colours. And then you drive it (robot) over. And it makes Mary Had a Little Lamb…..It sings Mary Had a Little Lamb. It plays the notes. Based on the colors. You can create anything in the world.”*

9.4 Interview With Music Therapist

The music therapist was interviewed the last whereas in the original plan, they were to be interviewed twice, first in the beginning of the co-design and then in the end. Keeping the research timeline in mind, the researcher decided to have one long detailed co-design session with them in person in Toronto.

The therapist provided the researcher with an insight into the diverse nature of music therapy as a profession in Canada, highlighting that every practitioner is trained differently and thus, their approaches may vary slightly. Though the profession is regulated to some extent, it's not as stringent as other clinical therapy procedures. They introduced various frameworks and models of music therapy, including the Psychodynamic approach rooted in psychotherapy or cognitive behavioural therapy, the music-centered Nordoff-Robbins approach, the Bonnie Method based on guided imagery with music, and Neurologic music therapy, which is grounded in neuroscience, focusing on how the functions of music drive change.

These are different clinical therapy methods suggested by different psychology pioneers that modern day music therapists follow in their practice. All these approaches might be different in design but have the same goal of creating meaningful improvements or changes in the lives of their clients. According to the music therapist, it's important to recognise where the change is coming from or what the goals might look like.

They shared with the researcher that they work from a psychodynamic and neurological music therapy perspective keeping the relationship between the client and themselves at the core. In parallel, their knowledge of the brain also comes in handy in using music effectively.

The music therapist has had a good amount of experience working with children, particularly those with autism. In these sessions, they use many visuals as they believe this can be a tactile experience for the kids and help integrate their senses. According to them, for many neurodiverse children, the visual aspect is immediate and helpful. They use a board with session plans divided into four choices. On the other side of the board are pictograms that allow the children to choose what they want to do and play. They use these pictograms to put their choices back on the board. This structured and routine activity provides predictability while also allowing for autonomy in choosing the order of activities. It's also another way for the children to communicate what they want to do and create a schedule.

The music therapist suggested that they often receive referrals for children who struggle with speech, language, and communication and have found that their communication skills are often good, just not verbal. Their goal in their practice is to create a safe space for the kids to express themselves through music therapy. To achieve this, they choose instruments that can help with breath control, phonation, and different embouchures of speech production. Being intentional with instruments encourages turn-taking and communication skills. For instance, big instruments like the piano can be used for collaborative play, helping children interact with each other in a positive way. Being aware of the kind of musical responses they provide to these children can support a good relationship with them.

The music therapist further explained the possible benefits and uses of music therapy for neurodivergent children:

> *"I think quite often people will think about music therapy in the sense of self-expression and emotional processing. And I think those things are all very true. I think that psychosocial piece can really be unlocked through music. And just give another dimension to what might be difficult to communicate with. Within the means of what the child has. But yeah, we can also work on speech production. Language skills. Communication skills. I think sensory motor skills are also something that is a goal area that we work on. So fine motor, gross motor coordination.*
>
> *I see a lot of tiptoe walking and things like that. So really using the music intentionally to help them feel the ground. And be more confident in the way that they navigate the world. And also safety. There's an argument around ableism, but we live in a world where walking heel-toe is going to be safe for them."*

The therapist suggested that there are other functional cognitive things that could be addressed with music therapy such as targeting specific things about attention when playing games like stop and go when the music starts playing. The therapist suggested participating in similar activities takes a lot of cognitive effort for children.

They suggested that there are a lot of things a child can focus on but they prioritised a few based on time and resources. They would address the child's immediate needs more versus the larger things based on the number of sessions they get with the child. The therapist added that parents pay for music therapy from their own pockets so their point of view and needs for their children impact the nature of the therapy and its goals for their child.

The therapist talked a little about what it is like to be a parent of a neurodivergent child:

> *"I will never know what it's like to be a parent with a child with autism at this point in my life. So I can only imagine the overwhelming feelings that have come with the responsibility of this new life. And what that means. So there are different facets. There's the actual music therapy clinical work in the session. But then there's holding space for the family. And the dynamics that happen there. And sometimes my parents will come to me. They're like, the child really enjoys music. I've heard there are many benefits."*

The therapist explained that the goal of therapy is not always focused on clinical work or attempting to aid self-regulation for the child. Sometimes, the objective is simply to have a good time with the child. They highlighted that engaging children in repetitive practices could be challenging, and this difficulty could extend to music therapy as well. Therefore, they had emphasized the importance of balancing these elements, recognizing the need for flexibility in approach and acknowledging that not every session may need to be oriented towards clinical outcomes. This perspective had underscored the multifaceted nature of therapy and the necessity to align with the child's individual needs and capabilities.

When enquired if their child clients are proficient in playing an instrument, they suggested that they have had all kind of children come to them with varied levels of music knowledge and they find working with both very interesting.

The therapist informed the researcher that their clients were given complete freedom in how they wanted to play the instruments. The children were encouraged to be as creative as they liked, whether it was by taking apart an instrument without breaking it or finding innovative ways to play within the bounds of the child's safety. The therapist had further elaborated on working with children in a mode referred to as "open play." This approach allowed the children to explore and experiment without rigid constraints, fostering a safe and nurturing environment that prioritized the children's comfort and creativity while maintaining their well-being. They further explained working with children in an open play:

> *"The kiddos I've worked with get very adventurous. Some things come out that they might be unable to communicate with words. Different objects might mean different things. A lot of imaginary play can happen. There's sometimes testing the limits with the strength that they have.*
>
> *You'll have parents sit in on sessions. Saying, no, play it this way. Let's see how many ways we can play something. Let's be playful. Especially with adults, we lose our sense of play. We lose the idea of being free and creative. As we experience more life."*

While social communication and speech are important goals of music therapy, it can sometimes also be attachment and bonding for the child and their caregiver and having a moment of meaningful interaction. When asked about the reasons why parents brought their children to music therapy, the music therapist explained that it may be related to their child's connection with music or singing. For instance, if music helped the child access their voice or if they frequently experiment with sounds at home. Additionally, some children may enjoy playing with toys that have musical elements, so music therapy can be a helpful tool. The therapist couldn't determine if one reason is preferred over the other.

In terms of creative arts therapies, the therapist suggested that it is often what the child is asking for. Different therapies can activate different cognitive functions within the child and if they have a preference for a vertain media, the parents will try to facilitate that for their child. Usually, according to the therapist, these preferences are noticed by the parents in their child that leads them to bring their child to music therapy or any other type of creative arts therapy. Sometimes it's what other medical professionals notice when they suggest music as a way to activate a sensation in the child. Some therapist also recommend combined mediums with other professionals like art therapists or play therapists based on the need or interest of the child based on prior experience with their clients. As per the therapist, the multi-modal way of the creative arts is exciting and has different benefits as well.

The researcher moved to do therapy online after the pandemic and shared their experience of it:

> *“It is very different. It is not my favourite with kids. It is a lot of parent coaching and defining what the goals are. Also figuring out how to do simple things such as unmute themselves or share a screen.”*

The researcher inquired about the potential overwhelming effects of music therapy sessions on children. The music therapist responded that it can be overwhelming at times, as everyone has different needs. In particular, being in a new environment with musical instruments can be overstimulating, especially when children are without their parents. This can be challenging for kids during their first session. The music therapist explained that in these situations, they often allow the child to play their preferred instrument and may bring the parent back into the room to help them calm down. Additionally, they may use techniques such as proprioceptive, reinforcement or a weighted blanket to aid in relaxation.

The music therapist was overall positive about multimodal activities with different kinds of technologies and said that they are slowly getting more experience with it. They believed that multi-sensory tools can be very approachable for children.

When asked if the robot interaction would make the kids overwhelmed, they said that it was a possibility and depends on the inclusion criteria and who the child was and their cognitive flexibility.

Music therapist thought that within music therapy, different practitioners are using similar tools in terms of usage of tangible media and colours and creating music and sounds in an interactive manner, especially for executive function or self expression for composing. According to them, this tool could be explored further using different instruments, especially for someone who might have difficulty with instruments or for someone who is super interested in technology.

They also mentioned a musical app for mental health where one can generate and make music on an app through easy touch interactions. The music therapist thought that this robot interaction can easily be used in a music therapy setting or art therapy or in music education. They suggested exploring the psychosocial aspect of this tool and finding out how someone can have their own agenda for it, like musicians, music educators or music therapists. They found the tool very versatile.

When asked if something like this would be complicated for children, they said that kids are smarter than adults think they are and if the correct instructions are given in a clear way for them to understand, they would be able to do it. Where it gets complicated is not that they can't understand it, but rather the other things happening in the brain that might prevent them from using this tool.

They suggested that a tool like this can have different levels. One child might be able to play with a certain difficulty level of this interaction. A simpler version of this tool could be designed for someone who only starts with one colour or two colours. They could use two colours of markers to create a simpler pattern. The therapist said that this could be true for any child, neurotypical or neurodiverse.

According to the therapist, too much choice could be too exciting sometimes and believes there is safety in structure and boundaries. They also believed that it is an interesting experiment and something that parents are looking for away from screens. They were overall appreciative of the idea that technology isn’t the main focus of this interaction design.