

How's that sound?
Co-designing neurofeedback game audio with
children

by
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Abstract

Many children struggle with mental health challenges such as anxiety and attention deficit hyperactivity disorder. Neurofeedback games, like Mind-Full, use portable brain-computer interfaces to help children cope by developing self-regulation skills. These games work by receiving electroencephalographic (EEG) input and relaying that information to users. In theory, feedback may be visual, auditory, tactile, or some combination. In practice, most games are visual. As users gain focus, the game visuals respond on-screen in real time. The reliance on visual feedback can create difficulties in the field—schools are often noisy and filled with distractions, and some children are uncomfortable sitting in silence with adults. Incorporating sound into neurofeedback games could improve usability and, potentially, outcomes. However, there is a basic problem—adult researchers cannot assume to know what sounds might appeal to young users. This prompts important questions: How can children contribute to the co-design of sounds for a neurofeedback system? What sounds do children think would be suitable for each game? In this thesis, I look to children to guide the development and evaluation of sounds for neurofeedback games. I report findings from a co-design study to create sounds for Mind-Full. I worked with 16 children as design partners over five sessions at a school in Vancouver, Canada. I present results from each session, discuss limitations, and review theoretical implications. In this work I find that children can participate in the co-design of sound via *ideation, clarification and elaboration of ideas*, and *evaluation of sounds*. The contributions of this work are a set of practical guidelines for co-design with children, an enhanced version of Mind-Full Wind, a summary of the ways in which children can contribute to the co-design of sounds, and insight into the tension between teacher's roles as design partners and facilitators. This work may be helpful for future researchers and designers interested in running co-design studies related to sound.

Keywords: Co-design; Children; Sound; Games; Neurofeedback; Brain-Computer Interfaces

Dedication

To Vince.

You jump, I jump.

To my parents, Charles & Linda.

I'm sorry I always maxed out our home internet.

To my Granny, Norma.

Thanks for showing me the value of a laugh.

To my dog, Apollo.

If you can read this, bark once.

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List of Acronyms

ADHD	Attention Deficit Hyperactivity Disorder
BCI	Brain-Computer Interface
EEG	Electroencephalogram
SFU	Simon Fraser University
TECI Lab	Tangible, Embodied, Child Interaction Lab

Glossary

Brain-computer interface	A system that uses measurements of brain activity to control a digital interface
Co-design	A design technique that involves working with users on the ideation, development and evaluation of new technology
Electroencephalogram	A technique of measuring brain activity that uses sensors placed on an individual's scalp to measure the brain's electrical impulses
Self-regulation	Using one's body to control brain state

Chapter 1. Introduction

Mental health challenges such as anxiety and attention deficit hyperactivity disorder (ADHD) affect significant numbers of children (James et al., 2015; Subcommittee on Attention-Deficit/Hyperactivity Disorder, 2011). Without treatment, children experiencing these challenges may struggle in the classroom, leading to negative impacts on learning and self-esteem. Self-regulation—the ability to control one’s body and brain to adapt to emotional states—can help manage symptoms of these mental health challenges. Research suggests that neurofeedback-based training can support children’s acquisition of self-regulation skills (Gruzelier, 2014; Lubar et al., 1995; Mandryk et al., 2013).

Previously, neurofeedback treatments relied on the use of complex medical equipment to measure user’s brain activity and provide them with real-time feedback. The emergence of low-cost commercial EEG headsets, however, brings with it the potential to significantly improve the accessibility of neurofeedback treatments. Researchers are currently exploring the effectiveness of these devices for practicing neurofeedback with children (Johnstone et al., 2017; Mandryk et al., 2013). One of these systems is Mind-Full, which uses a NeuroSky EEG headset paired with a game on a tablet device (Antle et al., 2015). Mind-Full has demonstrated effectiveness for improving children’s capacity for self-regulation in studies in both Asian and North American contexts (Antle et al., 2019, 2015).

In exit reports from a recent research study by Antle et al. (2019), social workers facilitating the intervention indicated the Mind-Full could benefit from the addition of game sound. During the study, they reported some behavioural difficulties: children often close their eyes to relax, preventing them from seeing their performance while playing; and they often appeared uncomfortable sitting in silence with adults. They also noted environmental difficulties: most studies take place in schools, which are noisy and filled with distractions. Through a review of the literature, I hypothesize that adding sound to Mind-Full could potentially reduce these challenges by providing students with multimodal feedback and reducing the risk of distractions by improving children’s sense of immersion.

To explore the potential advantages of including game sound, it is necessary to first design and add appropriate sound treatments to the system. There is little guidance in the literature on designing sounds for neurofeedback games for children. Further, as an adult researcher, I cannot assume to know what sounds might appeal to young users. For this reason, I look to children to guide me in the development and evaluation of game sounds. In this work I collaborate with children as design partners. This presents at least two challenges. First, there are few examples of researchers using co-design to develop sounds for multimedia experiences such as tablet games. Second, there remains questions about the ways in which children can contribute to this type of work.

The following manuscript describes a co-design study to create sounds for Mind-Full. I worked with 16 children as design partners over five sessions at a school in Vancouver. This work responds to the research questions: (1) In what ways can children contribute to the co-design of sounds for a neurofeedback system? and (2) What sounds do children suggest for the Mind-Full Wind neurofeedback system?

There are four contributions of this work. First, I outline a set of guidelines for co-design with children based on the literature. Next, I describe an enhanced version of Mind-Full Wind that includes children's sound ideas (wind, bird, and stone sounds) for use in future studies. Third, I provide a summary of the ways in which children can contribute to the co-design of sounds. Finally, I offer insight into the tension between teacher's roles as design partners and facilitators. I break down the content of the thesis into the following chapters.

Chapter 2–Related Work

Chapter 2 provides a review of the literature in which I ground this work. I begin by providing an overview of neurofeedback, detailing the relative merits of commercial neurofeedback devices, and current work using neurofeedback to address children's mental health challenges. Next, I describe the neurofeedback application Mind-Full, and outline two studies that explore its effectiveness to help children learn to self-regulate. Following this, I provide context on the use of sound in interactive multimedia experiences and suggest two specific ways in which the addition of sound could benefit users of the Mind-Full system—by providing multimodal feedback and increasing players sense of immersion. Next, I describe co-design, and outline foundational work using this

design method with children. I conclude with a practicable list of guidelines to help guide my decisions in the design of this research study.

Chapter 3–Methodology

Chapter 3 outlines the methodology used in this work. I begin by providing an overview of the study, including details on the research setting, participants, research materials and procedures. Next, I detail the steps I took in advance of the study, including preparing ethics documentation, and meeting with school staff and researchers to explain co-design and outline the study details. Following this, I describe the procedure, first by providing a high-level overview, and then a detailed summary of each individual session. I include the expected learning outcomes for children, goals for the co-design task, and any emergent design changes required. Next I review my data collection methods and the corresponding data analysis techniques. I conclude this chapter with a section on the known limitations of this methodology, and highlighting the steps I took to address them.

Chapter 4–Results

Chapter 4 summarises the findings of this co-design study. I begin by responding to my first research question identifying ways in which I observed children participating in the co-design process—specifically through *ideation, clarification and elaboration, and evaluation*. I note how children contribute to the design not only by describing sounds with words, but also by expressing ideas using their body. I also detail the aspects of co-design that children appeared to struggle with. Next I respond to my second research question, summarizing sound ideas put forward by children for Mind-Full Wind, and describing how these ideas developed through the co-design process. Finally, I conclude this chapter with a summary of other observations which may be helpful for future researchers interested in co-design with children.

Chapter 5–Discussion

Chapter 5 offers a detailed discussion of my findings from this work. I begin by relating main findings back to foundational work in the co-design literature and address the generalizability of my findings. Next, I review strengths and limitations with this

research methodology encountered over the course of running the study. Then, to explore and validate whether an enhanced version of Mind-Full could be helpful for children learning how to self-regulate in a school using a neurofeedback game, I propose an experimental research design that could be applied in a future study. I conclude this chapter by revisiting the guidelines put forward in Chapter 2, reflecting on which recommendations worked well, and what changes would be helpful for researchers running co-design studies in the future. I include specific suggestions for researchers interested in running co-design studies for sound.

Chapter 6–Conclusion

Chapter 6 of this manuscript provides a summary of this work. I review the research goals of this study and the main findings. I provide an overview of the topics addressed in the discussion section and conclude with a brief analysis of the contributions of this work.

Chapter 2. Related Work

2.1. Neurofeedback

2.1.1. Mental Health and Children

Many North American children struggle in school due to mental health challenges such as anxiety and ADHD. Research suggests that anywhere from 5% to 19% of children experience anxiety challenges (James et al., 2015), and approximately 8% of children experience attentional challenges at some point during development (Subcommittee on Attention-Deficit/Hyperactivity Disorder, 2011). These can have persistent and negative impacts on learning and self-esteem (Klassen et al., 2004; Murphy, 2005). Interventions at a young age may be particularly beneficial as children's cognitive and emotional faculties are still developing (Chronis et al., 2006). And while pharmacological alternatives can, in some cases, be effective, they do not work for all children (Barbaresi et al., 2007; Chronis et al., 2006). An alternative, less invasive, strategy is to teach children self-regulating techniques such as deep breathing and meditation (Black et al., 2009).

Below, I review the literature on neurofeedback—that is, technologies that measure and report brain activity in real-time. I detail the relative merits of commercial neurofeedback devices before discussing the use of neurofeedback to address children's mental health challenges. Finally, I describe the neurofeedback application Mind-Full, and two related case studies from Nepal and Canada.

2.1.2. Neurofeedback Background

Research suggests that neurofeedback-based treatments can be helpful in the acquisition of self-regulation skills (Gruzelier, 2014; Lubar et al., 1995; Mandryk et al., 2013). This process involves using a Brain-Computer Interface (BCI) to practice control over one's brain activity. The human brain contains billions of neurons. When these neurons fire they generate electrical signals. Certain patterns and frequencies are associated with specific mental states—such as when an individual is relaxed or focused. Researchers have developed a variety of techniques to monitor brain activity, including functional magnetic resonance imaging (fMRI), magnetoencephalography (MEG), and

electroencephalogram (EEG). In this work, I focus on neurofeedback using EEG data. This is a non-invasive method that uses sensors placed on a user's scalp to detect signals from their brain.

Neurofeedback training involves enabling a user to observe their EEG signals in order to understand their (otherwise imperceptible) mental activity. Research suggests that, with practice, users can learn to control the frequencies their brain produces (Vernon et al., 2003). In doing so, they can also learn to regulate and control affective and cognitive processes associated with anxiety and attentional ability (Gruzelier, 2014).

Commercial EEG Headsets

To date, most research on neurofeedback relies on the use of complex EEG equipment (Gruzelier, 2014). These systems require users to be fitted with many electrodes at specific spots on their scalp. Sensors remain in place using a fitted cap. The connection between the scalp and the electrode is facilitated by a conductive gel. Due to the sensitive nature of this equipment, neurofeedback treatments were, until recently, confined to laboratory settings. The recent emergence of low-cost consumer EEG headsets has increased the accessibility of this technology and empowers researchers to easily run neurofeedback interventions in the field. Headsets manufactured by companies such as NeuroSky¹ (Figure 1), Muse², and Emotiv³ open new, exciting avenues for applied research.

There is a trade-off between portability and data quality with these new headsets, however. On the one hand, portable headsets are mobile, which means researchers can use them without being in a lab context, or requiring complex set up process. On the other hand, portable headsets have fewer sensors than laboratory-grade equipment, which means we observe only a limited section of brain activity. Portable headsets also often use dry sensors. While these are easier to use, not requiring users to use conductive gel on their scalp, they are also less conductive. Further they have increased sensitivity to environmental interference, which results in noisier brainwave data. Fortunately, evidence shows portable EEG headsets have significant test-retest validity

¹ <http://neurosky.com/>

² <http://choosemuse.com/>

³ <https://www.emotiv.com/>

(Rogers et al., 2016). In other words, they offer unbiased measurement of brain activity, albeit without the full range of measurement offered by laboratory-grade equipment and with higher variance.



Figure 1. Photo of BrainLink Pro portable EEG headset by NeuroSky.

With the development of portable EEG technology came a new wave of applications that use brain activity in novel ways. Some examples of early work with these headsets involved using commercial BCIs as controllers for video games (Nijholt et al., 2009; O’Hara et al., 2011). More recently, researchers began exploring the potential of portable BCI gaming for neurofeedback purposes (Johnstone, 2013). Several studies evaluate these systems as a therapeutic tool to help children with mental health challenges; of particular interest are studies that demonstrate the potential for neurofeedback tools to help children with anxiety and attentional challenges.

Commercial EEG Neurofeedback for Children

Below, I review key citations in the literature on commercial EEG neurofeedback for children. For each, I discuss research design considerations such as sample size, outcome measures) and review their findings. I then revisit each study to discuss the precise mechanism of feedback, such as the use of visuals.

Lim et al. (2012) looked at neurofeedback games for children with ADHD. In this study, 20 participants between the ages of 6-12 with ADHD played a computer game called Cogoland. To play, users wore a NeuroSky EEG headset that measured their level of attention. The more a user focused, the faster their avatar in the game would move and the easier it would be to complete the task. The goal of the first task was to move around a virtual space as fast as possible. The goal of later tasks involved making the avatar jump for fruit by pressing a key while the child moved the avatar with their mind. Participants in this study used the game for three training sessions per week, for a total of eight weeks. Children completed a Stroop test immediately prior to each game-play session to calibrate the system. Following the eight-week intervention, children completed a maintenance phase in which they participated in monthly booster training sessions for three months. To evaluate changes in children's attention level over the study, participants were measured on a behavioural rating scale completed by their parents (ADHD-RS⁴). Measurements were completed four times: pre- (week 0), post- (week 8), and at follow up test points (weeks 20 and 24). Teachers were also asked to complete a behavioural rating scale, but the non-response rate was too high to analyze the results. Researchers found that the participants in this study showed significant improvements in inattentive symptoms of ADHD. The results indicate parent ratings of the combined ADHD scores significantly improved from pre-test to post-test and were maintained (but not impacted by booster sessions) at both follow-up points. There was also a statistically significant improvement in mean parent-rated hyperactive impulse score and combined inattentive and hyperactive impulse score between the start of the study and week eight, with no statistically significant change at 20 weeks compared to eight weeks. There were several limitations to this study. First, there was a small sample size with relatively high attrition (of the 20 individuals in the study, only 17 completed the intervention). Second, there was no control group. Finally, parents completing the rating scales were not blind to treatment.

Johnstone et al. (2017), looked at the effects of neurofeedback training on children's working memory and inhibitory control. In this study, 85 children between the ages of 7-13 with clinical or subclinical ADHD played a computer game called Focus Pocus. This game consisted of a series of 14 sub-games, four for training working

⁴ ADHD Rating Scale

memory, four for inhibitory control, and six for practicing neurofeedback. Of the neurofeedback games, two were created to encourage the following mental states: *relaxation*, *attention*, and *zen*. To play, participants wore a NeuroSky headset to measure EEG signals, and used their mind to control wizard-themed games. This was a waitlist-controlled study, with participants randomly allocated to either the treatment or waitlisted group. Researchers evaluated participants using experimental tasks and behavioural assessments at pre- and post- intervention. Tasks to measure children's cognitive abilities included: auditory go-nogo, the auditory oddball task, visual counting span, the auditory digit span task, and resting eyes-open and eyes-closed tasks. Behavioural assessments were measured using survey instruments for parents, including the ADHD-RS, Conners 3-P⁵, CBCL⁶, and WIAT -II⁷. Additionally, two individuals other than the child's parents were asked to also complete the ADHD-RS, one had to be a teacher and the other could be any adult close to the child. Participants in this study completed 25 sessions of training at home over six to eight weeks. There were no differences between group or condition for the cognitive tasks. Results of pre-post- comparisons suggest improvement in ADHD symptoms based on parental ratings on behavioural assessments. However, teacher and the other adult ratings suggested that only the subclinical ADHD group showed improvement. This study had several limitations. First, parents were not blind to condition; however, the participants' teachers and other adults were supposed to be (although this could not be verified). Second, there was no dedicated control group. Third, there was no follow up test point to see if children maintained the improvements seen in parent's behavioural assessments. In this work, the authors also investigated children's engagement and enjoyment while using the system. They found that children's interest waned over time, stressing the importance of creating neurofeedback systems that could maintain children's interest over long treatment periods.

Mandryk et al. (2013) addressed the challenge of maintaining children's interest by converting off-the-shelf video games into custom neurofeedback games. Their goal was to help improve children's motivation to practice neurofeedback over an extended period. In this study, 16 children between the ages of 8-17 played off-the-shelf games

⁵ Conners 3rd edition–Parent

⁶ Child Behavior Checklist

⁷ Wechsler Individual Achievement Test–2nd edition

with a custom-built overlay. The children selected were all diagnosed with fetal alcohol syndrome, which the authors note is often accompanied by a diagnosis of ADHD. Their system used NeuroSky EEG input to alter the games' display graphics, adding a textured layer which obfuscated its visuals if the user did not maintain a desired brain state. Participants practiced with their system two to three times per week over 12 consecutive weeks in a research lab setting. Typical sessions lasted 60 minutes and children played for approximately 30-45 minutes. Using a survey measure following the 12-week intervention they found that the participants enjoyed playing the games, wanted the textured layer to go away, and felt they could control the presence of the overlay. While this study did not look at children's ability to improve their self-regulation skills as a result of neurofeedback over time, participants did show improvement in their ability to control their brain activity (and the textured overlay) during gameplay. Their findings suggested that children remained intrinsically motivated to practice neurofeedback over repeated sessions because they found the underlying games engaging enough to maintain their interest. By improving the gaming experience, children's likelihood to complete the number of sessions needed for effective neurofeedback training may be improved.

Schoneveld et al. (2016), looked at neurofeedback and anxiety in children. In this study, 136 children with anxiety from six different schools between the ages of 8-13, played a videogame called Mind-Light. This game uses a NeuroSky EEG headset to measure a user's brain state. When relaxed, a light in the game shines and illuminates certain aspects of the surroundings as one completes puzzles. Children were randomly assigned to play Mind-Light or an alternative puzzle game called Max and the Magic Marker. The games were played individually, but groups of 7-19 children sat in a common room during the intervention. Assessments of children's anxiety were done using the SCAS-C⁸ for children, and SCAS-P for parents. Researchers found that all participants showed improvements in anxiety symptoms based on child and parental ratings on the SCAS from pre-test to post-test, but there were no differences between groups. This study was limited by the fact that groups of children played together in a single room, and possibly experienced a contamination effect. It is also possible the

⁸ Spence Children's Anxiety Scale

results were affected by children’s expectations, as participants were led to believe that both games could benefit symptoms of anxiety.

Before proceeding to the next section, I briefly consider the precise mechanism of feedback in each study. As discussed above, neurofeedback works by receiving input from an EEG device and relaying that information to users. This feedback can potentially be visual (e.g., responsive, pixelated avatars), auditory (e.g., sounds synced with brain activity), tactile (e.g., haptics), or some combination of these.

In Lim et al. (2012), the mechanism of feedback was visual. When users focus, their avatar moves around a virtual, on-screen space. The published study makes no mention of game sound. In Johnstone et al. (2017) the mechanism of feedback was also visual. For example, the “levitation speed” of a user’s wizard avatar depends on the relaxation level. Again, the published study does not mention sound. In Mandryk et al. (2013) a custom neurofeedback interface was integrated with off-the-shelf video games. Again, the mechanism of feedback was visual. When users lose focus, the screen fills with a textured layer that obscures gameplay, as demonstrated in Figure 2. While the games had sounds they were the same as the original off-the-shelf games and did not provide any feedback related to brain activity.



Figure 2. The textured layer superimposed over an off-the-shelf video game from Mandryk et al., 2013.

The mechanism of feedback was also visual in Schoneveld et al. (2016). Users watch a screen to observe the game. When the EEG headset records brain activity associated with being calm, the user receives a reward. Of note in this study, however, is that because the children were playing as a group, it was necessary for the researchers to try to limit distractions and disturbances. The researchers mention children wore headphones to hear game audio and block out external sounds; however, the researchers do not discuss what sounds were used and how these may have affected the results.

Overall, existing research into the use of portable EEG systems to practice neurofeedback shows promise to improve children's mental health outcomes. Most studies rely almost exclusively on visual feedback. Other feedback mechanisms exist, such as sound, but to date few have been incorporated into research materials. When they have, there is little information provided. It is unknown what difference feedback mechanisms of have on children's experience when playing a neurofeedback game.

2.1.3. Mind-Full

In order to explore neurofeedback, researchers in Simon Fraser University's Tangible, Embodied, Child Interaction Lab (TECI) developed their own application, Mind-Full (Antle et al., 2015). Like the systems described above, Mind-Full is a portable EEG neurofeedback system. It was designed to help improve mental health outcomes for children ages 5-11 (Antle et al., 2015). Mind-Full was built as an affordable, portable, and effective neurofeedback system that could help children learn self-regulation in a school environment. It has the potential to improve the accessibility of neurofeedback treatments for children for whom it would otherwise be prohibitively expensive or unavailable due to lack of lab-based EEG facilities.

There are three different versions of Mind-Full, each with graphics developed with specific research contexts in mind, Mind-Full Wind, Mind-Full Wild, and Mind-Full Sky. However, they all have the same underlying functionality. Each Mind-Full system comprises a NeuroSky EEG headset connected to an app running on an Android mobile device. A single EEG sensor in the NeuroSky headset rests on a user's forehead and measures electrical impulses from a user's brain. The headset also has an earclip that provides a reference point to reduce environmental electrical noise in the data. EEG data is then transmitted to the app wirelessly via Bluetooth.

Incoming data is processed by NeuroSky's proprietary algorithm to identify brain activity patterns associated relaxation and attention, indexed on a 1-100 scale. The generated relaxation and attention scores are used to control the Mind-Full games. Each version of Mind-Full has three sub-games, two for practicing relaxation, and one for practicing attention. In Mind-Full Wind, for example, the pinwheel and paraglider games are built for children to practice creating EEG signals related to relaxation, and the stone game is mean to practice creating EEG signals related to attention (Figure 3). If a user's

score is greater than a threshold number, a game animation is triggered. This feedback allows users to observe changes in the brain over time. If a user maintains this brain state for a set period, they are rewarded with game tokens to track their progress. For example, in the Mind-Full paraglider game, the default period a user must remain relaxed to receive a reward is 11 seconds. The threshold number and period for a reward can be customized in real-time by an adult facilitator.

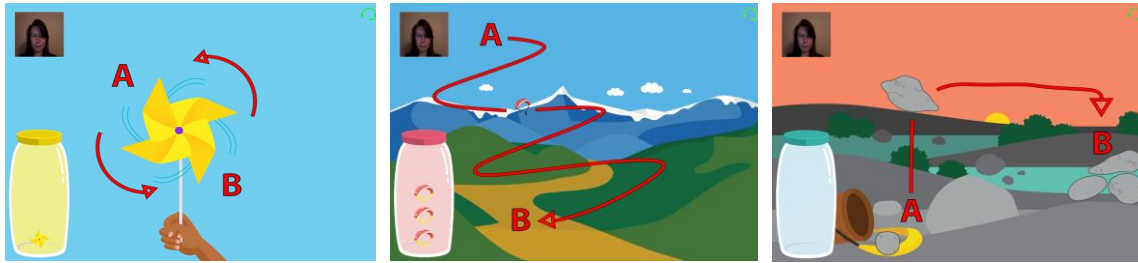


Figure 3. Illustrations from Mind-Full Sky. © Antle, used with permission.

Researchers have investigated Mind-Full in North American and South Asian contexts. The system has demonstrated effectiveness for improving children’s ability to self-regulate and focus—even outside of using the application—after approximately 20 sessions. The following section briefly outlines the research studies completed to date.

Nepal Study

Mind-Full was originally developed for children in Nepal who had experienced trauma resulting from poverty and civil unrest (Antle, Chesick, Sridharan, et al., 2018; Antle et al., 2015). Trauma is known to affect children’s development (Price et al., 2013), and the resulting anxiety and attentional challenges may lead to decreased educational outcomes. In order to explore whether a tablet-based neurofeedback intervention could be used to help these children, Antle et al. (2015) ran a two-group field study using Mind-Full at a non-profit school in Pokhara Nepal. This work aimed to respond to research questions relating to whether children can successfully learn to use neurofeedback-based tablet games, whether they can control the games by practicing self-regulation of anxiety and attention, and whether they can transfer these skills to contexts outside of playing the game (Antle et al., 2015).

Participants in this study were 20 girls ranging in age from 5-11 years old. These children used the Mind-Full system for approximately ten minutes, three to five times per week, over the course of six weeks (Antle et al., 2015). Data collected during this

intervention included data logs from children's game play, qualitative survey data of observable self-regulation behaviours at pre-test, post-test, and follow-up time points using a custom survey tool developed by the research team, and written reports from teachers and counselors.

Overall, the children were able to successfully complete the target number of sessions using Mind-Full. Researcher observations suggest the children were able to use their bodies to calm and focus their minds to play the games. The results of the behavioural assessment surveys suggest that children were able to transfer these skills to other contexts at school. At pre-test, the intervention and waitlist control groups were found to be equivalent. The behavioural measures on the survey of children's ability to transfer anxiety self-regulation training were different at different assessment points for the intervention and waitlist control groups, with the treatment group exhibiting better self-regulation of anxiety. The behavioural measures on the survey of children's ability to transfer attention training were different at different assessment points for the intervention and waitlist control groups, with the treatment group exhibiting better attentional abilities. All but one behavioural measure was found to be statistically significant at post-test. The researchers found that at the two-month follow-up, children were able to maintain their increased self-regulation skills.

Although there were limitations to this study—for example, the sample size was small, there was no control group at follow-up, and the participants, teachers, and counsellors were not blind to condition—the results were encouraging. Mind-Full appears to be a viable neurofeedback intervention for children, with potential to be a treatment for those experiencing anxiety and attentional challenges.

Canada Study

More recently, researchers from the TECI lab worked with a school district in Canada to test whether a neurofeedback intervention could benefit North American children with mental health challenges. Antle et al. (2019) ran a two-group waitlist-controlled field study using Mind-Full at two elementary schools in Canada. This work aimed to address research questions related to whether children can learn to self-regulate anxiety during Mind-Full gameplay, whether children can transfer their ability to self-regulate to contexts outside of playing Mind-Full, and whether the children in the

intervention group (i.e., those that used Mind-Full) demonstrate reduced anxious behaviours compared to those in the control group (Antle et al., 2019).



Figure 4. A child using Mind-Full. © Antle, used with permission.

Participants in this study included 20 children (14 boys, six girls), ranging from 5-8 years old. These were selected from a group of 32 children identified by teachers and school staff as having severe anxiety and/or attentional challenges. Current publications based on this work are only on the subsection of study participants who demonstrated high levels of anxiety. Children were grouped into matched pairs based on grade/gender/anxiety challenges and personal characteristics. Individuals in each pair were randomly assigned to either the intervention group or the waitlist-control group. Participants used the Mind-Full system for approximately ten minutes, three times per week, over the course of seven weeks. Sessions were led by facilitators, trained to work with children with mental health challenges. One trainer was a social worker. The other was an educational assistant trainee.

Data collected during this intervention included teacher and parent qualitative survey responses. Data included observable self-regulation behaviours at pre-test, post-test, and follow-up time points using a validated survey tool (BASC-3⁹), as well as a

⁹ Behavior Assessment System for Children—3rd edition

custom survey instrument, cortisol tests for measuring stress levels at pre-test and post-test, written reports from facilitators, and interviews with facilitators and teachers.

Children were able to learn to control the game by self-regulating their anxiety, as measured by their relaxation score from the EEG headset during gameplay. The results of the behavioural assessment surveys and interviews indicated improvements in children's ability to self-regulate anxiety at school and home and a decrease in anxious behaviors at home. Cortisol tests showed a decrease in participant's physiological stress levels (Antle et al., 2019).

In exit reports, facilitators for the Burnaby study indicated the Mind-Full system could benefit from the addition of game sound for several reasons. First, they reported that children often appeared uncomfortable sitting in silence with the adult facilitators during the sessions. They observed that children felt a need to fill the silence in the room by talking or making noises. These behaviours take children's focus away from self-regulation tasks; including game sound could discourage children from engaging in this type of behaviour. Second, the facilitators noted that children often closed their eyes while trying to maintain a relaxed brain state. In doing so, they were no longer able to see their game performance. The addition of game sounds could allow children to continue practicing neurofeedback, even when they are not able to see the tablet game. Third, schools are noisy and filled with distractions. To effectively learn to control their brain state, children must focus inward. This can be difficult amidst unpredictable external disturbances, particularly for those with attentional issues (Gumenyuk et al., 2005). I propose that adding sound to Mind-Full could help mask these disturbances and help make the intervention more suitable for real-world school settings.

2.2. Sound

2.2.1. Sound Background

Sound can create immersive, emotionally powerful experiences (Byun & Loh, 2015; Leman, 2007). Some studies report that sound can help people improve focus, support learning, and elicit strong affective responses in listeners (Bishop et al., 2008; Byun & Loh, 2015). It plays an important role in interactive media and can drastically change the way one interprets visual images (Collins, 2013). Sounds can make

children's experience using an application more enjoyable (Shneiderman, 2004). These may consist of sound effects, ambient audio, dialogue or music (Guerraz & Lemordant, 2017). Despite the importance of sound in user experience, the literature often overlooks it (Bishop et al., 2008).

In the following section, I discuss the role that sound could play in a neurofeedback tablet game for learning self-regulation such as Mind-Full. Specifically, I suggest the addition of sound could provide the user with multimodal feedback and increase their immersion in the system.

2.2.2. Sound as Feedback

Designers can use sound to provide feedback on performance. Positive reinforcement sounds have been shown to reduce the learning curve in games (Collins, 2013). There even exists a genre of games that is entirely audio feedback-based (*AudioGames*, n.d.). Audio feedback may involve adding or removing a sound, or modifying a sound already present in the game. Some examples of parameters that can change to indicate game performance include pitch, timbre, volume, and tempo (Droumeva et al., 2007; Kaae, 2017). When designing audio feedback, researchers suggest that the relationship between players' actions and the sounds should be self-evident and possible for a user to predict (Collins, 2013). For example, if a user repeats an action (e.g., rings a bell), they expect a similar sound to occur (e.g., a chime).

Feedback through multiple senses is called multimodal feedback. When used appropriately, multimodal feedback can be helpful for learning (Kalyuga, 2000). By providing information through different sensory channels, it increases the likelihood the user will receive and understand the feedback (Jørgensen, 2017). Multimodal feedback helps ensure the user receives information when one of the senses may not be available, such as if an individual is visually attending to something else. In the case of Mind-Full, children often close their eyes when asked to relax, thus rendering visual feedback ineffective. In some cases, combining feedback from different senses can have a greater effect than one would otherwise obtain from each of the individual sensory modalities separately (Kohlrausch & van de Par, 1999).

There has been some exploration into the impact of combined audio and video feedback on game performance. Jørgensen (2017) explored how audio supports the usability of interactive games. In their study, 13 participants (demographic information not provided) played a game. Researchers observed how individuals responded when they removed audio feedback during gameplay. Participants used the system with sound for approximately 15-20 minutes and without sound for a further 10-15 minutes. Participants reported feeling a loss of control when there was no sound. One described it as a sensation of being “left completely in the dark” (Jørgensen, 2017, p. 166). They found increased reaction times and decreased usability when multimodal audio and visual feedback was removed.

2.2.3. Sense of Immersion

Conventional wisdom holds that small changes to the audio in multimedia experiences can dramatically alter the user’s feelings of immersion and emotional involvement in the work (Bullerjahn & Güldenring, 1994). Also, Mind-Full was developed for use in a school-environment. Classrooms are busy, noisy, and loud. This can make practicing self-regulation difficult, particularly for those who may already experience attentional challenges such as ADHD. Byun and Loh (2015) demonstrate that sound can improve feelings of immersion and engagement with learning technologies. In this context, immersion may help to aid focus by reducing the impact of external distractions while practicing neurofeedback.

Ermi and Mäyra (2007) define three types of immersion, challenge-based, imaginative, and sensory. Challenge-based immersion occurs when a game is suitably challenging for a user’s abilities. Imaginative immersion is when a user becomes absorbed in the game’s story. Sensory immersion in games occurs when information from the system overrides “the sensory information coming from the real world, and the player becomes entirely focused on the game world and its stimuli” (Ermi & Mäyrä, 2007, p. 45). The addition of sound to Mind-Full may require headphones, which themselves could reduce external stimuli and improve children’s feelings sensory immersion within a game.

Video game scholars Nacke et al. (2010) looked at the physiological effect of sound in first-person shooter games. In this study, 36 undergraduate students (29 male,

seven female), played a video game while having their electrodermal activity and facial muscle activity recorded. Participants played the game in counterbalanced order for approximately ten minutes each under different conditions: sound effects on/off, and music on/off. Each session was approximately two hours long. Following game play, participants completed the GEQ¹⁰. While researchers found no significant differences in physiological recordings, they found significant differences in qualitative reports on all aspects of the GEQ, including measures of immersion, tension, competence, affect and challenge. Participants were more likely to report positive dimensions of the GEQ (flow, positive affect, competence and challenge) with game sound on. With game sounds off, participants experienced fewer negative dimensions (negative affect and tension). Further they concluded that sound improved feelings of immersion, and generally led to a more positive gaming experience. In sum, this work suggests that including sound and music can affect users' feelings about a gaming experience.

Lipscomb and Zehnder (Lipscomb & Zehnder, 2004) looked at how the addition of a soundtrack to a video game affected user's experience. Specifically, the researchers wanted to explore if players' perceptions of a game changed due to the presence of music. They also explored how music impacted players' experience, and whether attributes such as gender or age affected responses. In this study, 76 participants (25 male, 51 female) were randomly assigned to either play a video game with music, play a game without music, or listen to their own music while playing. Following gameplay, users evaluated their experience verbally using a semantic differential response scale. They rated gameplay across 21 attributes (e.g., "active", "dangerous", "exciting", "strange"). Results suggested a significant difference between groups for some of the scales. Participants in the game-with-music condition rated the "colourful" attribute higher and the "relaxed" attribute lower. This suggests the specific type of game sound can impact player's experience. Gender and age were significant factors for some, but not all, of the response scales. This suggests players' responses to sound in a game can vary by demographic attributes. Based on this, it is important to consider the target users of a game when designing game sound.

Wharton and Collins (Wharton & Collins, 2011) looked at the effect of personalized music in games. Researchers asked fifteen participants, ages 19-30 (eight

¹⁰ Game Experience Questionnaire

male, seven female) to select music to listen to while playing the video game Fallout 3. Participants could choose to listen to music from a prepared playlist, music from their own MP3 player, or play in silence. When participants reached predetermined checkpoints, they could change their selection. Participants used the think-aloud protocol as they played, and researchers asked open-ended questions periodically to assess feelings of immersion within the game. They found mixed results. Some players reported music was helpful in masking distractions and external sounds, increasing their feelings of immersion. Other participants reported a more immersive gameplay experience when playing in silence. This suggests that users should have the option to play either with or without sound depending on their preference. This is in line with recommendations by other researchers related to user experience when designing sound for children's technology (Shneiderman, 2004).

Beyond this, the researchers made another noteworthy finding. This work indicated that participants who chose to listen to their own songs were unable to predict music from their own library that would increase immersion or enjoyment during gameplay—including those familiar with the game. According to the authors, “players lacked experience in understanding the complex interplay between music and a game, and were unsuccessful in choosing music that they thought would help them to achieve a desired effect” (Wharton & Collins, 2011, p. 1). Players reported that it was important for the selected audio to complement the game visuals. Audio that did not seem appropriate for the game context led to feelings of anxiety. This suggests that one should design audio treatments with a specific game in mind. This is in line with findings of other researchers (e.g., (Paul, 2017)) who recommend sounds be grounded in reality to maximize a sense of immersion in a game.

2.3. Co-Design

As identified in Section 2.1.2, most portable neurofeedback systems rely almost exclusively on visual feedback. However, my exploration into the literature on sound suggests that game sound can greatly impact user experience. And while some research mentions game sound (Schoneveld et al., 2016), researchers rarely provide details on how specific audio treatments are chosen and how such treatments may influence neurofeedback performance.

My review of the literature in section 2.2 suggests three important objectives when selecting audio treatments for neurofeedback games. First, sounds should provide information to a user. This renders the experience multimodal, such that sound feedback is self-evident and predictable. Second, sounds should improve feelings of immersion in the game. This reduces distraction and focuses players' attention on game performance. Third, sounds should be enjoyable and align with children's preferences and tastes. Responses to sound can vary depending on own personal background, experiences, or culture (van Geelen, 2017). This may be especially true when designing for children, because they have unique tastes and preferences (Druin, 2002) (Scaife & Rogers, 1998). It is also of particular importance when designing neurofeedback games, which require repeated exposure over extended periods of time (Johnstone et al., 2017).

This third factor poses a serious design problem: Adult researchers cannot assume to know what sounds forward are appealing to children. Just because a researcher believes a given sound is informative and immersive does not mean it will be suitable to children's taste. To move with the development of sound for Mind-Full, I look to children to guide the development and evaluation of game sounds. In this section, I describe the role children can play in the design of new technology, with an emphasis on a specific design technique, co-design, that integrates users into the design process.

2.3.1. Co-Design Background

Cooperative design (also known as co-design) was developed based on participatory design traditions first practiced in workplaces in Europe. This design technique was intended to democratize the design process (Muller & Kuhn, 1993), giving workers a say in the technologies they use on a day-to-day basis (Kensing & Greenbaum, 2012). Users and designers work as partners in the design process. By developing new workplace technologies together, the aim of co-design was to improve workers' quality of life and acknowledge their expertise.

This design technique has since been used extensively in human-computer interaction research. In practice, co-design can vary. At its core are two key values: (1) users themselves play a critical role in the design process and (2) there is mutual learning on the part of both the researchers and users. Researchers endeavour to

understand users' lived experience, while users' endeavour to identify their own needs and the technologies needed to satisfy those (Kensing & Greenbaum, 2012).

Co-design typically starts early in the development process. It involves designers working collaboratively with users over an extended period. For users to meaningfully contribute to the final design, it is important that their voices have power. Researchers gather participants' ideas and feedback and continuously implement them into the design. The goal is to create new technologies that designers might otherwise not imagine. Ideally, this leads to the development of systems better suited to users' needs.

More recently, researchers have modified co-design techniques to work with children (Druin, 2002). Children differ from adults, having their own tastes and interests. Co-design allows researchers to benefit from children's experience and insight. It allows them to discover early in the design process what they may need and want from technology.

Co-design has a number of inherent challenges, and it is not always obvious what a co-design process looks like. For example, in what ways do adults' relationships with children change when taking part in design activities? what role do children play in the design? and how does one measure success? The answer to these questions vary depending on the context. In the following section, I summarize research that explores the role children can play in the design of new technologies, identify known challenges of co-design with children, and outline guidelines that will form the basis of this co-design study.

2.3.2. Review of Co-Design with Children

Co-design with children requires a clear project scope, including problem definition and goals. Scaif and Rogers (1998) provided early explorations into work with children to develop new interactive media games. They note how previous researchers working with children focused largely on gathering feedback from children on completed projects. They were driven to practice informant-based design after testing one of their own projects with children, who reported finding it boring. By redesigning the system with children's input, they hoped to create a system children found more engaging. During this co-design task, they worked with children ages 9-11 to design a system, called

ECOi, to help students understand food chains. First, children worked in pairs to create low-tech prototypes. Children designed versions of the game specifically for children a year or two younger than themselves. Next, a developer built these ideas into software. During the development process, children were brought in as liaisons to evaluate prototypes in progress. The authors identify several generalizable suggestions for working with children as co-designers. For example, they recommend having a clear definition of the problem and the domain and problem from the outset. They also stress the importance of outlining clear criteria to decide which ideas to accept with regards to system goals.

Druin (2002) described four roles that children can play in the design process: *user*, *tester*, *informant*, and *design partner*. Each role has a unique goal, a unique relationship between children and adult researchers, and a unique relationship to the technology being developed. As *users*, children work with technology while adult researchers observe. This is typically done once development of the technology is complete and is meant to better understand the way children use it. This can aid in the development of future technologies. As *testers*, children work with prototypes of new technology and help researchers identify challenges with the system. This is often done near the end of the development process, and researchers may revise the system based on their findings. As *informants*, children play a more active involvement in the design process. Researchers might ask them early in the development stage for sketches and ideas, or observe them using similar technologies. Following development, researchers once again ask children for feedback on the final product. As *design partners*, children have the most active role in the design process, taking an active role from early stages of development. As design partners, children can be equal stakeholders alongside adult researchers. Both *informant* and *design partner* roles can be viewed as forms of co-design.

In her work with children, Druin (1999) adapted a research approach referred to as *cooperative inquiry* for this cohort. Druin applied these methods in research studies in schools, as well as a lab at the University of Maryland. The lab hosted an on-going intergenerational design team that included two faculty members, two graduate students, two staff members and six child design partners between the ages of 7-11 years old. They identify children between the ages of 7-10 as ideal for this type of design process because of their ability to reflect on ideas as well as their lack of preconceptions on

design. They suggest this cohort is old enough to provide researchers with detailed information, but not yet at an age where they may be hindered by social pressure. Their lab met twice per week, as well as for a summer two-week intensive (Druin, 1999). Cooperative inquiry methods involve collaborative brainstorming and low-tech prototyping techniques. For example, the *Big Paper* technique gathers small groups around large sheets of paper to collectively brainstorm through drawing (Walsh et al., 2010). The *Bags of Stuff* approach has children use crafting materials supplied by the researcher to assemble low-tech prototypes (Guha et al., 2013).

Central to their work is idea elaboration—children’s ideas take the project in new directions as they develop (Druin, 2002). Sessions begin with warm-up activities, and often conclude with large group discussions to share ideas. Afterward, the adult researchers remain to discuss the day’s activities. Typically, one adult plays the dedicated role of interactor with the children, helping to encourage discussion and asking questions to encourage children to elaborate on their thoughts (Druin, 1999). Druin’s research suggests that interactors should not be tasked with taking observational notes, as this can make children uncomfortable. Instead, they recommend another adult does note-taking for the group. Data collected from cooperative inquiry often includes examples of the low-tech prototypes, children’s notes, and researcher observations.

One early example of a project they developed using cooperative inquiry is *Kid pad*, a zooming story-telling tool that enables children to collaboratively create stories (Druin, 1999). The tool was developed by an intergenerational design team of educators, computer scientists and 40 children, ages 8-10, working in New Mexico public schools. Another example is *PETS (Personal Electronic Teller of Stories)*, in which children use robotic animal parts to build and act out stories developed by the University of Maryland’s intergenerational design team (Druin, 1999). In their experience working with children, the team found children are more willing to share ideas in co-design activities in a familiar, comfortable environment, e.g., at the child’s home or school. They note how difficult it can be for children and adults to develop design-partner relations because of the traditional power structure that exists between these two groups, and that building these relationships can take as long as 6 months (Druin, 2002).

Researchers have since built on Druin’s early work with children. For example, Guha et al. (2004) developed a method of cooperative inquiry specifically for working

with children between the ages of 4-6. They recognize that children of different ages may require co-design techniques adapted for their development stage. Younger children may struggle to participate in less-structured activities and brainstorming process. They refer to this modified version of cooperative inquiry as *Mixing Ideas*. And while this technique is not directly relevant because of its focus on young children, the researchers include a number of lessons learned that would benefit my research.

Guha et al. (2004) present *Mixing Ideas* as a case study from their time working with a group of 11 children on a co-design project. Twice per week they held hour long sessions over four weeks. Their goal was to have children come up with ideas on how to change a space in their classroom. First, the children worked one-on-one with an adult to come up with their own ideas and drawings. In the next stage, children mixed their ideas together in small groups by writing them on larger pieces of paper, allowing them to share their ideas and remind themselves of suggestions they had come up with previously. During this stage there were never more children in the group than there were researchers. The children and adults agreed verbally how to mix ideas together. The groups continued this process by combining ideas until there were only two ideas remaining. Finally, all 11 children came together and rearranged cut-outs of pictures from these two ideas and taped them together in new ways, children were then invited to draw out this new version onto a large piece of paper. While some of the ideas do not appear to be represented in the final project, the process of elaboration on earlier proposals influenced the final concept. The researchers concluded their study by debriefing with the children, asking what they liked during the process and what they found difficult.

From this study, they offer five lessons learned: (1) children need structure to collaborate during brainstorming; (2) in co-design it is important that children feel that they contributed ideas to the final project; (3) drawing can be helpful for children expressing themselves; (4) adults working one-on-one with children can be an important part of a co-design process; and (5) adults' ideas proposed while facilitating conversations are an integral part of the intergenerational design process, and their ideas should be considered equally valuable for the final design (Guha et al., 2004, p. 40).

In recent years, Druin's lab at the University of Maryland has not only proposed new co-design techniques (Walsh et al., 2010), but also acknowledged challenges with their earlier methods. Guha et al. (2013) published a retrospective titled "Cooperative Inquiry Revisited," in which the researchers reflect on what they've learned since their original publication. They point out there is no one single way of doing co-design with children, reminding readers that use of specific cooperative inquiry techniques is often determined by factors such as group dynamics and the researcher's goals.

Co-design has been practiced extensively by other researchers, based on the techniques developed within Druin's lab. For example, Read et al. (2002) ran a single-session co-design study with 50 children between the ages of 8-10 to create a new website interface for a school. Children worked in a total of six groups. Each group consisted of five to 11 children, as well as one researcher, and one or two adult facilitators from the school. Prior to the activity, the researchers met with the adult facilitators to explain the adults' role in the project. Each group had their own table in a shared space to work at. The researchers video recorded the activity. They began by explaining the design task, then running a learning activity and icebreaker session, followed by the brainstorming and research sessions. The children concluded the day by creating a paper prototype of the website. Following the activity, the researchers held a debriefing session with the adult facilitators. This work was evaluated using qualitative questionnaires, video recordings, and observations by the researchers and adult facilitators. They note that some parts of this research did not go quite according to plan, for example, children found it distracting when researchers took notes during group work. They also observed that certain groups required more hands-on guidance from the adults than had been expected.

The researchers suggest that participant contributions to the final product in co-design can be viewed as a continuum (Read et al., 2002). Child and adult participants contributed more (or less) to the final design based on factors such as participant environment, knowledge, skills and security. Environment consists of both cultural and physical factors, including room location, size, the ambient lighting, furniture, seating arrangements as well as the culture of the organization and individual's status within the organization. Knowledge consists of participants understanding of the task and the design domain, this includes both the children and the adults. Skills consist of children's cognitive abilities, ability to remain on task, motor skills for contributing to drawings and

written activities, and group work skills. Security refers to children's comfort level working with their teammates and group dynamics.

Researchers use co-design not just to create new design ideas but also explore conceptual models and ideas. Woodward et al. (2018) worked with children to design conceptual models for new intelligent user interfaces. They collaborated with seven children over four sessions spanning two weeks. Each session was 90 minutes long. Participants ranged in age from 7-12 years old. Each session consisted of 45 minutes of design time followed by 15 minutes of group discussion. The researchers found that co-design with children revealed conceptual models that were different than existing solutions. For example, previous work in child-computer interaction of intelligent user interfaces focused largely on improving recognition and accuracy of results. However, children in this study did not prioritize accuracy, rather, when the interface did not understand a user's voice command they simply wanted the system to be more forthcoming and conversational. This work demonstrates that children can generate ideas for abstract problems.

Little has been written on using co-design to create audio for games and multimedia applications. One exception is McElligott et al. (2004), who worked with visually impaired children to co-design audio-based toys and video games. They argue game designers often see audio as an afterthought in design, despite it being critical to users' experiences. They note audio is particularly important for individuals with visual impairments. In their paper, they present three projects co-designed with children. Each involved working with children between the ages of 3-12 with visual impairments. Each project involves three co-design sessions with groups of three to five children. The first project led to the creation of a game in which a user locates a sound using a joystick. The second project led to the design of a toy for altering a user's voice in real time. The third project led to the development of audio tactile toys that enable children to play with recorded voices using textile interfaces. The researchers do not provide sufficient detail about their methods in their write-up for me to draw inspiration from their methodology; however, this work demonstrates the feasibility and relevance of co-design for audio. The researchers suggest that not only does thoughtful sound design make games accessible to visually impaired students, it also to boosts the experience for sighted children. From my review of the literature, I found no evidence of a study using co-design with sighted children to create sound for a tablet-based game.

2.3.3. Known Challenges with Co-Design for Children

Ideally, co-design with children supports development of innovative technologies. In practice, there are several known challenges with this design technique. It is important to keep these in mind when planning co-design activities so researchers may attempt to reduce their effect.

First, developing technologies using co-design means that researchers have less control over the final product. The best possible outcome is that children come up with ideas that researchers themselves have not considered, and which better solve the problem they hope to address. However, children's ideas, while interesting, may not always be technologically feasible (Scaife & Rogers, 1998). Successful co-design requires researchers to keep an open mind about the final product and be open to adapting the project based on participant input.

Next, researchers may have to make decisions based on conflicting ideas proposed by children (Guha et al., 2004). If children's ideas are combined without reflection, there is a risk of creating a system that includes everyone's ideas but serves no one's needs well. This can be challenging because children may become upset if they do not feel they are being listened to, or if their ideas are changed by the group (Guha et al., 2005). It is important to ensure that children feel comfortable and included during co-design activities. It is a good practice to strategize methods of combining children's ideas in advance to ensure children's ideas are not overlooked.

Co-design means working with children as partners. However, researchers may confront traditional power structures between adults and children, particularly when working in schools (Druin, 1999). Building relationships with children can be especially challenging for researchers who do not have experience working with children. Collaborative relationships take time to build (Druin, 2002). However, this is logistically challenging; repeated sessions are time-consuming and difficult to schedule. When working in a school environment, for example, children may have holidays and limited class time to participate in co-design activities. At the end of the school year, children move to new classes, making follow up difficult.

Finally, researchers may face difficulty collecting high-quality data. Children often have trouble expressing themselves (Scaife & Rogers, 1998). They have limited

vocabulary and may lack the capacity to effectively describe their needs and wants during co-design activities (Druin, 1999). There can also be a dialogue problem, with researchers mistakenly believing they understand what children are saying, when they actually do not (Scaife & Rogers, 1998). Further, children are known to freeze or perform when they are aware they are being observed (Druin, 1999). More generally, children may behave differently during a research study than they normally would. This makes it difficult for researchers to assess the validity and rigour of co-design (Frauenberger et al., 2015). Researchers in this field are at risk of confirmation bias (Scaife & Rogers, 1998) or capturing underlying assumptions (Frauenberger et al., 2015).

2.3.4. Co-Design Guidelines

Based on my review of the literature on co-design with children, I compiled a set of nine guidelines for my study protocol. These consist of best-practices and findings identified by previous researchers.

Guideline 1–Choose an Appropriate Age of Children

In reviewing the literature, I found examples of children as young as four successfully participating in co-design activities (Guha et al., 2004). To guide my decision for selecting an appropriate age to work with, I look to the recommendations of Scaife & Rogers (1998), and work with children slightly older than the target users of my system. These children can relate to the target age but may be better able to express their ideas more clearly. This is helpful for gathering high-quality information on which to base new designs. The children in the study that lead to this work were between the ages of 5-8 years old (Antle et al., 2019). Therefore, I plan to work with children approximately eight or nine years old. This age is also within the range that Druin (1999) describes as ideal for co-design.

Guideline 2–Choose an Appropriate Environment

For children to effectively participate in co-design activities, it is essential they feel comfortable in the working environment (Read et al., 2002). Druin (1999) recommends running co-design sessions in a familiar space, such as a student's home or school as children are better able to express themselves in these contexts. From a logistical perspective, other criteria for selecting a space include having enough room to

run activities without disturbing others, and the necessary equipment such as tables and chairs.

Since schools meet the criteria above (children are accustomed to the environment, and there is access to large classrooms and equipment), it is a suitable environment to hold a co-design study. An additional benefit is that the children are already there. However, any location choice entails trade-offs and there are known challenges with working in schools. These include the existing power structures between children and adults, and scheduling constraints. For this study, I determined a school is the most appropriate environment; as the benefits outweighed the potential challenges (especially in comparison to alternative environments, such as a research lab).

Guideline 3–Determine Appropriate Frequency to Meet

There is no definitive best practice in co-design related to how frequently to meet and for how long. Some co-design teams meet for just a single session (Read et al., 2002). Others continue to work together indefinitely (Druin, 2002). Guha et al. (2004) met with children for one hour twice a week over four weeks. Woodward et al. (2018) met with children four times over two weeks. Based on my review of the literature, the number of sessions and the frequency with which the co-design sessions are held varies considerably by design task and project goals and resources. For the purposes of this research, I determined a minimum of four sessions are necessary: one to introduce the design task, one to gather ideas, one to gather feedback, and one to present the results back to children. Between sessions I also require enough time between sessions (minimum 1 week) to review children’s notes and incorporate design ideas.

Guideline 4–Determine Appropriate Group Size

Group size matters when practicing co-design. Activities can work with groups ranging in size from as small as two participants to as large as hundreds (Muller & Kuhn, 1993). However, running co-design sessions with large groups of children requires additional oversight. Druin (1999) recommends working in small groups, with at least two researchers assigned to each (one to take notes; another to facilitate). When there are more adults available, researchers may split the larger group into smaller teams while still maintaining a suitable ratio of children to adult facilitators. Read et al.’s (2002) co-

design session had a total of 50 children split into teams of five to 11 individuals, with two to three adults per team. Guha et al.'s (2013) co-design sessions involved a total of six to eight children and three to four adults, split into co-design teams of two to three children working with one to three adults. Woodward et al. (2018) had a total of seven children working with eleven adults, divided into an unidentified number of groups for co-design sessions.

Based on my review of the literature, there is no ideal number of children for co-design. However, it's important there are an adequate number of adult researchers available to facilitate breaking into small groups. When working with an existing group of children (such as in a school environment), the researcher may have little control over the number of participants. Since I plan to work with fairly young children, it is best to keep group size relatively small. I plan to have co-design teams of approximately three to five children each, with a minimum of two adults per team.

Guideline 5–Minimize Power Imbalance Where Possible

According to Bratteteig and Wagner (2014) “participatory designers are committed to sharing power with users and facilitate a design process where users are able to take part in all phases of a design project” (p. 2). Adults play an important role in the co-design process, but with their presence increases the risk of power imbalance. Based on the literature, researchers should make adult facilitators aware of this challenge prior to starting the co-design study. Even small changes in behaviour and comportsment among adults can make children feel more at ease. For example, Druin (2002) recommends using first names with children, wearing informal clothing, allowing children to ask questions without raising their hands, and taking research notes discreetly. I plan to discuss ways we can achieve this with the teachers and other researchers in advance.

Guideline 6–Ensure There is Mutual Benefit

Co-design must be mutually beneficial for researchers and participants (Bratteteig et al., 2012). According to Bratteteig (2012) in co-design “no participant normally knows everything: the ‘designers’ know about technical issues and design processes, while the ‘users’ know the domain and use context” (p. 132). It is therefore important that researchers do not simply gather information from children, but also

provide learning opportunities to them (Druin, 2002). This could be through learning new vocabulary or acquiring new knowledge of the domain. Warm-up activities in which concepts are introduced to children help them learn while also ensuring that all children can participate equally in the design task. The act of participating in a co-design activity itself can be a learning activity, allowing children insight into the design process while exploring new technologies and collaboration techniques (Druin, 1999). I plan to create learning outcomes for children for each session and introduce new concepts that build off previous weeks' sessions.

Guideline 7–Define the Problem and Domain

For individuals to contribute to the design of new technology, they must first be informed (Bratteteig et al., 2012). According to Scaife & Rogers (1998) “at the beginning of a project it is necessary to define the domain and learning problem” (p. 6). When working with children it is particularly important that these are presented in a way that participants can understand (Guha et al., 2004). This may involve using simple, age appropriate, language, or providing audio-visual learning aids to explain concepts. To ensure that participants understand, researchers should also check-in with them regularly and leave lots of time for questions and answers. For my study, I plan to dedicate the first session to ensuring children understand Mind-Full and the challenge that this work is addressing. Children will have an opportunity to see the technology in use first-hand. Further, I will leave time for questions from the children each session.

Guideline 8–Structure Activities in Advance

While co-design may take the design itself in an unexpected direction, it is important to have clear structure in place for each session. Activities should guide participants through the co-design task, providing constraints while attempting to not limit children's ideas. According to Scaife & Rogers (1998), “there should be clear criteria regarding what to accept, and what not to accept with respect to the goals of the system” (p. 23). This will help ensure that researchers maintain focus on the desired outcomes. When developing activities for children, researchers should keep their age in mind. For example, younger children may require additional guidance to collaborate during brainstorming, or may require alternative techniques, such as drawing, to help express their ideas (Guha et al., 2004). Researchers should also consider how to combine and analyze data in line with their desired goals for each session. For my study, I structure

each week's activity in advance so that children's contributions build on previous outcomes. I also draft an analysis plan to help guide my weekly review of the data.

Guideline 9—Ensure Children See Their Work Represented

Children must not only have a voice in co-design but the *power* to influence the final outcome (Bratteteig et al., 2012). While children's individual contributions may not always be recognizable within the final product, their contribution should play a role in its design (Guha et al., 2004). Researchers must help children recognize the role that they played in this process. For example, they might remind children of findings from previous sessions and be forthcoming about the criteria through which ideas were combined. I plan to take time at the beginning of each session to review the previous week's work, and to explain the process used to select sounds when showing prototypes to the children.

2.4. Research Motivation

Many children struggle with mental health challenges, such as anxiety and attention deficit hyperactivity disorder. Neurofeedback games, such as Mind-Full, use portable brain-computer interfaces to help children cope by developing their self-regulation skills (Antle et al., 2015, 2019). In theory, feedback for neurofeedback games may be visual, auditory, tactile, or some combination. In practice, most games are visual. The reliance on visual feedback can create difficulties in the field—schools are often noisy and filled with distractions, some children are uncomfortable sitting in silence with adults, while others prefer to practice self-regulation with their eyes closed. The addition of sound could allow children to benefit from multimodal feedback and reduce the risk of distractions by improving children's sense of immersion while playing.

Incorporating sound into neurofeedback games could improve usability and, potentially, outcomes. However, there is a basic problem: adult researchers cannot assume to know what sounds might appeal to young users. Children's preferences are unique. A strategy to involve children in the design process, co-design, would allow us to incorporate children's tastes and receive valuable feedback; however, there is little guidance in the literature on how children can participate as design partners to create sounds for tablet-based games. In the following chapter, I propose a methodology to help fill this gap in the literature.

2.4.1. Research Questions

This work addresses two exploratory research questions:

RQ 1: In what ways can children contribute to the co-design of sounds for a neurofeedback system?

RQ 2: What sounds do children suggest for the Mind-Full Wind neurofeedback system?

Chapter 3. Methodology

3.1. Summary

This is a co-design study to develop audio for Mind-Full, a neurofeedback system to improve children's mental health outcomes. My methodological design responds to my research questions. First, in what ways can children contribute to co-design for developing sounds for a neurofeedback system? Second, what sounds do children suggest as feedback for the games in Mind-Full Wind?

The study consisted of five co-design sessions with 16 children (ages 8-9) at a Vancouver school over a two-month period starting in December 2017. Activities were planned in advance. I used an emergent design approach, meaning I made small adaptations to the activities during the study based on teacher and researcher feedback. This helped ensure that sessions were suitable for the group. As researcher, I held the epistemological stance of constructivism going into this work. This theory recognizes participant's understanding of a task is based on their own unique experiences. My goal was to acknowledge this and recognize the impact this may have on children's contributions. Further, I recognize that as the leader of this study, my own background and role affected the outcome. When possible, I sought to be aware of this, make efforts to reduce this risk, and report my role in the activities.

3.2. Setting

The research site for this study was an International Baccalaureate private school in Vancouver, BC. This location was chosen for its existing relationship as a research site of Dr. Antle's. The school offered a design class for primary students, which meant I was able to work with children who already had some design knowledge. I was fortunate to work with the children and teachers as part of their normally scheduled class. The first two sessions were scheduled in a large room next to the children's design classroom. However, I knew in advance the location would change mid-way through the study due to renovations taking place. The room near the design classroom was located in a relatively isolated area of the school. When this area was no longer available, we used the children's normal classroom area and a small annex nearby. The

classroom was located in an open-concept part of the school and shared the space with other classes. The annex was a small, but fully enclosed room.

The school setting met many of the criteria outlined in **Guideline 2** (“Choose an appropriate environment”). Children were familiar with these spaces and would therefore feel comfortable. Further, each space had appropriate equipment to run the sessions (e.g., tables, chairs etc.). However, while the room for the first two sessions was spacious with few neighbouring classes, the open concept classroom used for the final three sessions made it challenging to run sound-related activities without disturbing others.

3.3. Participants

16 students from the school’s Grade 3 class participated in the study. The children (nine male, seven female) were between the ages of 8-9 years old. This age range aligned with **Guideline 1** (“Choose an appropriate age of children to work with”). I selected children to take part based on their enrolment in the Grade 3 design class at the school. This group recently completed a unit on sound and were about to begin a unit on cause and effect. Not all children took part in every session; some missed classes due to periodic absences from school.

I recruited participants through letters to parents and by asking the teacher to introduce the study in class. Participation was optional. I established consent from children’s parents through a form that accompanied the letter, which they submitted prior to the study. I established assent from children by reading a statement about the project and asking them to raise their hands if they agreed to take part during the first session. Children who did not provide consent/assent were able to join the normal classroom activities of another Grade 3 class. Three children in the class did not consent to taking part in the study. Another three children agreed to take part in the study but did not consent to us using images from video recordings of them in our reports and publications.

Some co-design literature emphasizes the importance of including special needs children in the co-design process, particularly when the technology is built for use by this group (e.g., Guha et al., 2008). Mind-Full was built for children with anxiety and

attentional challenges. However, for this study I did not do any behavioural screening prior to the study. I had access to this group of students, and it was important I work with the whole class rather than a subsection. There was no exclusion or inclusion criteria. All students from the class were eligible to take part. It is possible however, that some children in the class had attentional challenges, and teachers reported that several exhibited signs of anxiety.

Four female school staff members also participated in this study. While these individuals helped lead the activities, their ideas and suggestions also contributed to the final project design. The staff members included the children's classroom teacher and the school's design instructor. I asked all these individuals to sign a consent form in advance of the sessions since they were part of the co-design process.

3.4. Research Materials

I used the following research materials in this study: six Mind-Full systems for demonstration purposes; a video explaining the Mind-Full system; screenshots and images from each of the Mind-Full games; audio samples developed by the children; markers; large sheets of paper; audio recorders; two video cameras; and research protocol information packages for school staff.

3.5. Procedure and Tasks

3.5.1. Preparation

Approximately six weeks before the study, I met with the design teacher at the school regarding another research opportunity. Through this conversation I learned about the Grade 3 design class and their planned curriculum leading up to the end of the year. Together, we identified overlap between the children's current unit on sound, a future unit on cause and effect, and our lab's recent work on Mind-Full. The TECI lab wanted to add sound to Mind-Full, and this was an excellent opportunity to develop this work. I chose to focus on developing sounds for Mind-Full Wind specifically because it is the original game in the Mind-Full series.

After receiving permission to run this research at the school, I prepared the necessary ethics application. I suggested scheduling activities in the new year, but the school preferred not to overlap with future units. Since I was working within the constraints of the school's schedule, I had little control over the frequency with which I would meet with the children. We agreed to run a total of five design sessions, which was one more than the suggested minimum needed based on **Guideline 3** ("Determine appropriate frequency with which to meet"). In mid-November, I wrote and gathered the following documentation for SFU's ethics department:

- Ethics overview
- Letter outlining my study for parents
- Informed consent form for parents
- Informed consent form for teachers
- A script for teachers to read to children to tell them about the upcoming study
- A script to read to children to establish assent

As per **Guideline 4** ("Determine appropriate group size"), co-design benefits from a high ratio of adult-to-child design partners. I asked for support from other school staff to ensure an adequate ratio of adults to children. I hoped to have at least two adults for every five children. Since the total class size was 19, I ideally needed approximately eight adults available to work with the children if they all participated. Ultimately, there were four adults from the school, and four adults from SFU including myself involved; however, not all adults were available to attend each session.

Prior to the start of the study, I met with the design teacher and school staff who helped me lead the activities. I demonstrated Mind-Full, explained co-design, and outlined details of the proposed sessions. The study protocol (Appendix A) aimed to connect my research study to the design classes' unit objectives. I also addressed the potential power imbalance that may be present within the school, and introduced some techniques to minimize it, as per **Guideline 5** ("Minimize power imbalance where possible"). I later met with researchers from SFU to review the same information.

3.5.2. Procedure

Table 1. Session Dates and Goals

<p>(1) December 12 2017 – What is Mind-Full? In Session 1, I introduce children to Mind-Full (a mobile neurofeedback game to help children learn to self-regulate) and the design task.</p>
<p>(2) December 19 2017 –Sound & Games In Session 2, I introduce how sound is used in games to convey information, and we come up with ideas about the kinds of sound and feedback that could encourage other children playing Mind-Full.</p>
<p>(3) January 16 2018 – Sound Evaluation In Session 3, children evaluated sound treatments gathered for the pinwheel and paraglider games based on their ideas from Session 2.</p>
<p>(4) January 23 2018 –Sound Evaluation II In Session 4, children viewed a prototype app with the previous week’s sounds included. They continued evaluating sound treatments selected based on their ideas from Session 2 and identified ways to assess the enhanced system.</p>
<p>(5) January 30 2018 –Evaluation In Session 5, children see the final prototype and provide feedback on the co-design process.</p>

The study took part over the above five sessions. Sessions were typically held weekly, but there was a three-week break after Session 2 to accommodate the school’s winter holiday. The activities took place during children’s normal time for design class. Sessions were between 45 and 60 minutes in length. Each session had specific goals and outcomes, which are detailed later in this section. Although the content of the individual sessions varied, they mostly shared a common structure.

As per **Guideline 9** (“Make sure children see their work represented”), I began each session by reviewing the previous week’s outcomes. This reminded participants what they had learned, and demonstrated how they contributed to the design. This also gave me an opportunity to check in with participants to ensure I understood their ideas. Next, the class would take part in a group activity to introduce concepts and terms, as per **Guideline 6** (“Ensure there is mutual benefit”). Next, I would typically introduce the day’s co-design task. These tasks were typically completed in small groups, as per

Guideline 4 (“Determine appropriate group size”). Collaborative groups were determined by the teacher, based on existing classroom dynamics. Each group had an adult working with them to encourage participation, keep children on track, and assist with note taking. The groups changed each session. I concluded each session by recapping the day’s lesson, thanking the group for their help, and reminding children how their work contributed to the project, again as per **Guideline 9**.

3.5.3. Session 1

Table 2. Session 1 planned learning outcomes for children

<p>Children will...</p> <ul style="list-style-type: none">• learn how brain activity relates to feelings of stress, anxiety, and attention• be introduced to brain-computer interfaces that detect and display brain activity on a tablet device• experience controlling their brain activity using the <i>Mind-Full</i> neurofeedback system• see the link between brain activity (cause) and animations on the screen (effect)• reflect on how individuals around the world experience feelings of stress and anxiety• view ways in which research in Canada can affect children living in other countries• come up with initial sound ideas for the app

The goal of Session 1 was to introduce the children to the Mind-Full application and the design task. This was in line with **Guideline 7** (“Define the Problem and the Domain”). To respond to our research questions, the children first had to learn about neurofeedback and the goals of our research in a way that made sense to them.

This session was 60 minutes long and took place in the room next to the design classroom. There were three SFU researchers, three school staff, and the children’s classroom teacher present for the activities. 16 children took part in Session 1. Before starting the day’s activities, I obtained children’s assent by reading them the script approved by SFU’s ethics committee and asked the class to raise their hands if they agreed (Figure 5).

Next I began the educational portion of the session, as per **Guideline 6** (“Ensure there is mutual benefit”). I sat with the children as a group, and I spoke about Mind-Full and the design task. I introduced self-regulation, and the ways in which brain activity can lead to feelings of stress and worry. I asked children to share what they do to feel better when they are anxious. I noted anxiety is something children all around the world experience. I explained the previous research our lab completed in Nepal and Burnaby.

To make sure the children understood how Mind-Full works in practice, I also showed a short video explaining the system.

To ensure children understood Mind-Full I planned to give them each an opportunity to play it themselves. SFU researchers worked one-on-one with children at different table groups to help them put on the BCI headset and try the game. Unfortunately, due to technical challenges detailed later, few children were able to try the system that day.



Figure 5. Children giving assent by raising their hands in Session 1.

The remainder of the class engaged in the day's co-design activity. Children worked in groups to come up with sound ideas for the nine Mind-Full games (three from each: Mind-Full Wind; Wild; and, Sky). Table groups consisted of four children paired with one school staff member to take notes and keep them on task. I provided children with paper with printed screenshots from the games and felt pens. I also provided a short series of prompts for the adults to go through with the children, including "what sorts of sounds make you feel calm/not calm?" and "what sounds would go with each of the games?" I encouraged them to write answers and sound ideas on the paper. The SFU researchers were not involved in gathering ideas from children as they were busy

setting up individuals with Mind-Full. Following the co-design activity, I thanked children for their time and ideas before they left for their next class.

The SFU researchers stayed and debriefed on the day's activities. Due to the technical issues with having children try Mind-Full, the other researchers and I decided to adapt our plan for the coming weeks. We had two models of NeuroSky headsets that did not seem to interfere with each other. As such, I arranged for one SFU researcher to work with children two at a time. These children would play Mind-Full in a quiet space adjacent to the research area. One researcher observed that during the day's activities one child was particularly stressed because Mind-Full had not worked for them. Together, the researchers and I decided it would be helpful to review self-regulation strategies at the start of the following class for the benefit of this student.

Although today's session did not go according to plan, children still met all planned learning outcomes for the day, except for "experience controlling their brain activity using the *Mind-Full* neurofeedback system." However, all children had an opportunity to observe at least one classmate using the system. In terms of the day's research goals, this session provided children with foundational knowledge of Mind-Full. This was necessary to complete the design task during the remaining sessions. Data collected from this session included audio and video recordings, children's notes from the co-design activity, a recording of the researcher debrief, and my own research notes. Based on audio recordings and children's notes, I was able to compile a list of preliminary sound ideas for Mind-Full Wind, which provided a foundation for the following week's activity.

3.5.4. Session 2

Table 3. Session 2 planned learning outcomes for children

<p>Children will...</p> <ul style="list-style-type: none">• Learn about information that can be conveyed using sound, and how sounds can make people feel• consider the effect of using sound feedback in technology• further develop their ideas for app sounds• come up with new sound ideas for the app
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There were two goals for Session 2. First, to explain how game sound can convey information and second, to extend children's work by developing their sound

ideas for Mind-Full, identifying ways in which those sounds could change to provide feedback to users.

This session was 60 minutes long and took place in the large room next to the design classroom. The same SFU researchers, school staff and classroom teacher were present for all activities. 14 children were in attendance. Two children were absent. Due to the previous week's technical difficulties, one SFU researcher worked with children to give them an opportunity to play Mind-Full. For the duration of the session, children went, two at a time, to a classroom next door, to play the game for approximately 10 minutes each. As a result, this researcher did not take part in the day's co-design activities.

The first activity of the day was a review of the previous week's session. I emphasized the importance of self-regulation for anxiety, as per our the debrief from Session 1. Next we began the educational portion of the session (**Guideline 6**). First, I shared with the children how sound can be used to convey information and feelings. I asked about the sounds children heard that morning so they would see how they experience audio in their environment all the time. Next, we discussed how sound can guide actions (e.g., scary noises mean "be careful") and provide feedback (e.g., positive sounds in a game mean "you did something well"). I ran a short activity to apply these concepts. I played a series of audio tracks and asked the children to respond to the following questions: What do they think the sound is? Is it a type of sound effect (environmental sound) or music? What sort of meaning could this sound have? Does this sound make them feel a certain way?

I chose audio clips that would be familiar to children or have a meaning we could discuss. Examples included fire alarms (scary, warning, danger) and purring cats (comforting, safe). Music examples included a Disney song (slow, inspirational), and an upbeat classic dance song (upbeat, fun). Next I applied this to games by playing sounds from video games and asking children what they thought it could mean for gameplay (e.g., earning points, losing the game). The children and I spoke about the characteristics of these sounds. The class identified different ways that sounds could change, and how this could change their meaning. Based on my literature review, we talked about the following parameters that can change to provide feedback on game performance: volume, pitch, character (timbre), and tempo (Droumeva et al., 2007;

Kaae, 2017). I wrote these on a large piece of paper so the children could refer to them during the co-design exercise.

Before breaking into groups for the co-design activity, I asked children if they could recall the ideas they came up with for the games in Mind-Full Wind the previous week. Next, I reminded them of the ideas they did not remember and checked in to see if I had misunderstood any of their suggestions. The teacher assigned children to table groups of three or four. As with the previous session, each table had an adult facilitator to work with the children.

In Session 1, the co-design activity focused on identifying sounds for all three Mind-Full game collections—Wind, Wild, and Sky. For Session 2, I narrowed the scope to focus specifically on the games in Mind-Full Wind—the pinwheel game, paraglider game, and stone game. My goal was to develop children’s ideas from the previous week—specifically, to gather more information about what children imagined them sounding like. This would help me find suitable samples and explore how they could provide feedback. I provided children with images of each game, large pieces of paper, and felt pens. I included prompts for the adults to go through with the children for each game. These included: “For the sound ideas we thought of as a class, think about how the sound could change when someone is relaxing (in the pinwheel & paraglider games), or focusing (in the stone game)”; and, “Explain how the sounds change, and try to make the sounds out loud so we know what you mean.” Following this activity, I thanked children for their time and ideas. Children left for their next class.

Afterwards, two of the three SFU researchers stayed and debriefed on the day’s activities. The other researcher could not stay, and sent a short report via email later that day instead. The researcher assigned to use Mind-Full with children confirmed the process had been successful. We decided to continue this process until all children had an opportunity to play. While reviewing this week’s data I noted one child had turned off a handheld recorder. This was a problem since my research design relies on recorded data. I therefore adapted my plan. Instead of handheld audio recorders, going forward I captured data using recording apps on tablet devices. In this way I could set a passcode to prevent children from opening the device and stopping the recording.

Children met the planned learning outcomes for Session 2. The class explored the types of information that could be conveyed using sound and how these sounds make children feel. We looked at the use of sound in games, and the group came up with new sound and feedback ideas for Mind-Full. More children had the opportunity to play the game themselves, thus working towards the previously unmet Session 1 learning outcome. In terms of the day's research goals, this session provided children foundational information about sound. This allowed us to discuss and generate ideas for feedback for Mind-Full Wind. Data collected from this session included audio and video recordings, children's notes from the co-design activity, a recording of the researcher debrief, notes from the SFU researcher who had to leave early, as well as my own research notes. Based on this data I was able to find example sounds to bring in for children's evaluation during the next session.

3.5.5. Session 3

Table 4. Session 3 planned learning outcomes for children

<p>Children will...</p> <ul style="list-style-type: none">• develop their ability to evaluate new technologies• provide feedback on sounds gathered based on their previous suggestions• better understand how app ideas get created iteratively

The goal of Session 3 was for children to evaluate potential sound treatments based on their ideas from Session 2. This session was 60 minutes long and took place in the open-concept classroom. There were three SFU researchers, two school staff and the classroom teacher present for the day's activities. One of the SFU researchers was new to this study (they were replacing another researcher who could not attend the final sessions due to a scheduling conflict). 14 children were in attendance. Two children were absent. One researcher continued helping children play Mind-Full, two at a time. They did this in the classroom annex nearby and did not take part in the day's activities.

The first activity was a review of the previous two sessions. I spent a bit longer on review as several weeks had passed since the previous session. I reminded the children about the importance of self regulation. We practiced deep breathing as a group. Next, I led an activity with the children to review different types of audio in multimedia experiences. We also reviewed how changes to sound can provide

feedback. I expanded on what the children had previously learned by talking about the benefits of multimodal feedback.

The co-design activity in this session had children evaluate sounds for the pinwheel and paraglider games based on their previous ideas. As before, children worked in small groups along with an adult. Children at each table had a large piece of paper on which to take notes. I played a series of sounds using speakers placed at the front of the room. I played each sound at least twice. Children were asked to write a number on the piece of paper to indicate which sound they were listening to, and to indicate whether or not they liked that sound using a checkmark or some other symbol. I encouraged teachers to speak to children about the sounds as they went so I would have children's feedback on the audio recordings. After reviewing all the sounds of a specific type, I asked them to share which one (if any) they liked best for the game. This helped me identify whether I had understood children's ideas from Session 2. I provided children with four sound samples for the pinwheel game (three wind and one water—each of which was gathered based on feedback from the previous week) as well as four sound samples for the paraglider game (birds) and four music samples.

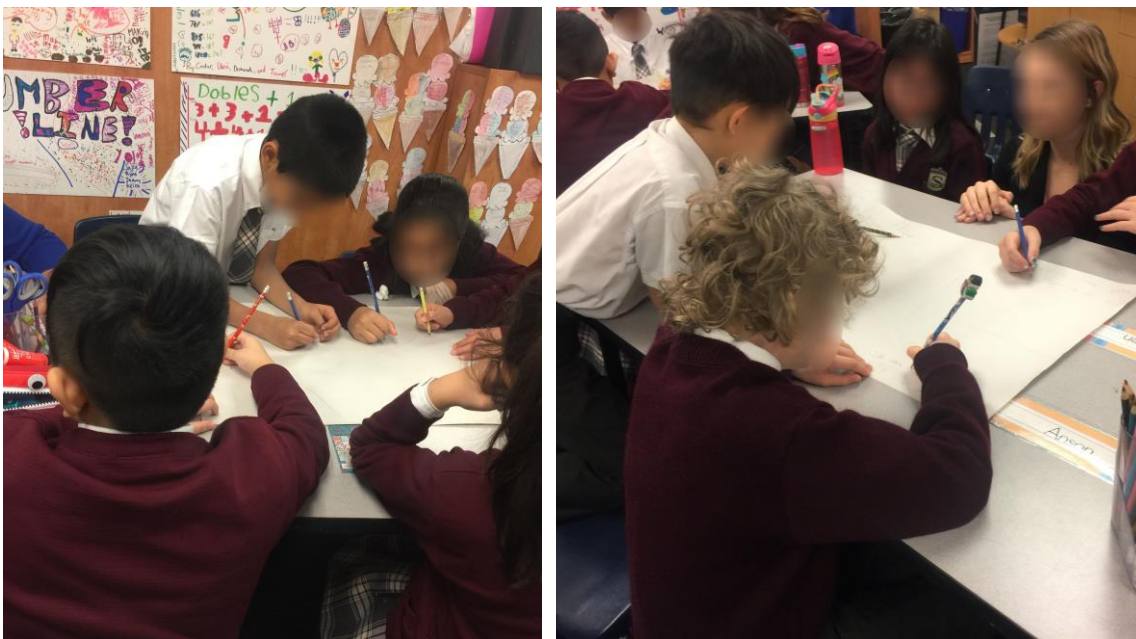


Figure 6. Images of children doing co-design activity in Session 3.

The sounds gathered for the games were selected because children had mentioned them in the previous session. I found samples using online sound databases

(e.g., Soundsnap, Freesound). I used two criteria for selecting samples: recordings had to be relatively high quality (i.e., sound isolated, easy to remix) and have an appropriate licence (e.g., creative commons). Finding creative commons music was more challenging, I had little success finding samples that I thought would work. I brought in a small selection that met children’s descriptions from the previous session (e.g., classical, jazz) to solicit feedback and clarify my understanding. This would help guide a refined search for music for the following week (Session 4). I concluded this activity by thanking children for their time and ideas.

After, the SFU researchers debriefed on the day’s activities. One researcher identified a challenge with the classroom’s seating configuration—the sounds were relatively quiet in the back of the room where one group was sitting. However, we were unable to increase the volume due to the neighbouring classes. This may have impacted children’s evaluations of the sounds. Given this challenge, I spoke to the classroom teacher. We agreed we should use the small annex (where children had been playing the Mind-Full game) for the following weeks’ sound evaluation sessions. The teacher also noted that 60-minute sessions were possibly a bit long for the children. I arranged to shorten the final sessions.

We met the planned learning outcomes for Session 3. Children evaluated the sounds we gathered for the Mind-Full system and provided feedback for us to review. With regards to the day’s research goals, this session allowed us to better understand the actual sounds that children described in Session 2. Data collected from this session included audio and video recordings, children’s notes from the co-design activity, a recording of the researcher debrief and my own research notes. Based on this data I was able to determine which sounds should be programmed into the prototype.

3.5.6. Session 4

Table 5. Session 4 planned learning outcomes for children

<p>Children will...</p> <ul style="list-style-type: none">• develop their ability to evaluate new technologies• provide feedback on sounds gathered based on their previous suggestions• better understand how app ideas get created iteratively• see their work incorporated into a real system.• identify ways to evaluate the system
--

The goals of Session 4 were to show children a prototype of the system, gather additional feedback on sound ideas, and brainstorm how to evaluate the game. Based on the teacher's recommendation, this session was only 45 minutes long and took place in the annex next to the open-concept classroom. This reduced distractions for children in nearby classes. There were three SFU researchers, two school staff and the classroom teacher present for the activities. 13 children were in attendance. Three were absent. As in the previous two sessions, one researcher helped children play Mind-Full, two at a time. This researcher worked in the open-concept classroom, since we were using the annex, and did not take part in the day's activities.

The first activity was a short review of what the class previously covered. Next, I showed the children a video prototype of the app with their sound ideas included. This allowed me to get children's thoughts on the sounds and feedback mechanism prior to coding them into the system. Since today's co-design activity was a continuation of the previous week's evaluation of ideas children came up with in Session 2, the class did the co-design task prior to the educational activity (which we did near the end of the session instead).

As in the previous week, I wanted to gather feedback on sound ideas for Mind-Full games— this week, specifically the stone game. I also wanted to revisit music ideas, as the previous week's samples were just for guidance. Once again, the class worked in small groups with an adult. The children sat on the floor because there were no tables or chairs in the annex. I placed speakers at the front of the room and children gathered around to listen. I played three rock sounds and a water sound based on children's feedback from Sessions 2 and 3. Given children's reaction to last week's sound examples, I took a closer look at the literature on music for relaxing. I found an example of a song designed to help children stay calm while in fMRI machines. It was specifically developed to help children feel relaxed (Vanderwal et al., 2015). I brought this in as an audio example for children to evaluate, as it was in line with children's previous suggestions of "piano", and "calming."

For the educational activity this session, I spoke with the group about how one could evaluate a system like this once it was ready. I asked children how they thought we could test it, and what sorts of questions they could ask another child trying it out. I concluded the session by thanking children for their time and ideas.

After, the SFU researchers debriefed on the day's activities. One researcher indicated the volume levels were improved in this new classroom configuration. The researcher working with pairs of children playing Mind-Full reported that all the children in the class had now had an opportunity to try out the system

The children met the planned learning outcomes for the day. Children evaluated the sounds gathered for the Mind-Full system and provided feedback. They also saw their work included in a prototype app. Since the children had all played Mind-Full, we had also met the learning outcome from Session 1, to have all the children try it. In terms of the day's research goals, this session allowed us to better understand the sounds children were referring to in Session 2. Data collected from this session included audio and video recordings, children's notes from the co-design activity, a recording of the researcher debrief and my own research notes. Based this data I was able to incorporate the sounds into Mind-Full.

3.5.7. Session 5

Table 6. Session 5 planned learning outcomes for children

<p>Children will...</p> <ul style="list-style-type: none">• share their ideas on the co-design activities• evaluate the enhanced application
--

The goals of the final session were to present the enhanced version of Mind-Full, debrief with the children about the co-design process, and gather feedback from selected children. This session was 45 minutes long and took place in both the open-concept classroom and the annex next door. Three SFU researchers, two school staff members, and the classroom teacher were present. 15 children took part in this session. One child was absent.

I began the session in the annex with a brief review of the previous week's activity. Next, I demonstrated the completed app to children. Sounds were based on the children's evaluations in Sessions 3 and 4. There was a wind sound for the pinwheel game, a bird sound for the paraglider game, and a rock sound for the stone game. In demo-mode (with simulated data) in Unity on my computer, I showed children how the sounds change as the user relaxes or focuses. I also showed them a version of the

paraglider game with musical composition based on the previous week's song included. Next, I asked the group a few open-ended questions about their experience practicing co-design. I wanted to better understand if the children recognized their role in building game sounds and find out which parts of the process they enjoyed.

After the group activity two children were asked to try the game and then share their feedback. These children were selected by their classroom teacher for their ability to provide good feedback. One at a time, they played the game in the annex, with an SFU researcher on hand to provide support. The researcher then posed open-ended interview questions to each child (Appendix B).

Meanwhile, the remaining children completed an activity to come up with their own ideas for neurofeedback games. Each child received a piece of paper and was asked to draw their own game and interactions. This activity was not part of the co-design process, as it was simply meant to occupy the class while the two children evaluated the system. These drawings were not analyzed. At the end of the session I thanked the children for their help.

Children met the planned learning outcomes for the day. Children gave feedback on the co-design process and evaluated the application. In terms of the day's research goals, this session allowed us to get children's final thoughts on the enhanced Mind-Full system and the co-design process. Data collected from this session include audio and video recordings, children's notes from the co-design activity, a recording of the researcher debrief and my own research notes. Based on this data, I was able to better understand children's responses to the co-design process and get feedback on the application.

3.6. Data Collection and Measures

In this co-design study, I collected a variety of data to support and validate my findings. Data included: audio recordings of sessions; audio recordings of researcher debriefs; video recordings of sessions; written notes from table activities; researcher's written notes; and an audio recording of an interview with the classroom teacher.

3.6.1. Audio Recordings of Sessions

The entirety of each session was recorded. For activities involving the whole class, a recording device was placed nearby to ensure children's voices could be heard. For small group activities, I placed recording devices at each table. For the first two sessions, I used handheld recording devices. Due to technical challenges with this equipment, I switched to using recording software on tablet devices for the final three sessions.

I used audio recordings to document what each co-design table group discussed while they worked. By listening to conversations afterwards, I was better able to understand each group's written ideas without having been present for the discussion. This was especially important because there were not enough adults available to have a dedicated note-taker at each table. Having a recorded version of each group conversation helped me respond to RQ 1 because I could hear the way children contributed to the co-design process. It also helped me respond to RQ 2 because I could hear additional context, and understand children's ideas which may not have been legible in the written notes. This helped identify which sounds to include in the final prototype.

3.6.2. Audio Recordings of Researcher Debriefs

Following each session, I had an open ended debrief with the other SFU researchers. I asked if they had any thoughts or feedback on how the session went. This helped me learn about any issues that came up during the session, and whether any activities did not work as expected. During the debrief we also decided on any emergent changes to the research design that may have been needed. Researcher feedback helped me respond to RQ 1 because they identified how children contributed to the co-design process when I was not present for that part of the activity.

3.6.3. Video Recordings of Group Activities

The entirety of each session was video recorded. These recordings helped me observe and contextualize classroom activities taking place during the audio recordings. For example, the videos allowed me to identify which child in a group was speaking at a

particular time, or if a child was doing something with their hands that was unclear from the audio alone (e.g., motioning towards something, or expressing an idea for a sound with their body). This helped me answer RQ 1 because it allowed me to gather information about children’s behaviour that was otherwise not evident in the data.

3.6.4. Written Notes from Table Activities

During co-design sessions, children and teachers collaborated on notes and drawings related to their ideas for new sounds (Figure 7). The first day’s notes were on normal printer paper with screenshots from Mind-Full printed on the top half. For subsequent sessions, I used large newsprint paper so children could write on it together. Written notes helped identify children’s main ideas from each session and allowed me to keep track of their opinions on specific sounds. By gathering the most important take-aways on paper, it helped to clarify and validate our findings. It affirmed evidence from the audio recordings about which ideas children preferred. I used this data as an example of how children can contribute to codesign of sound for RQ 1 and children’s notes were used to determine key responses to RQ 2.

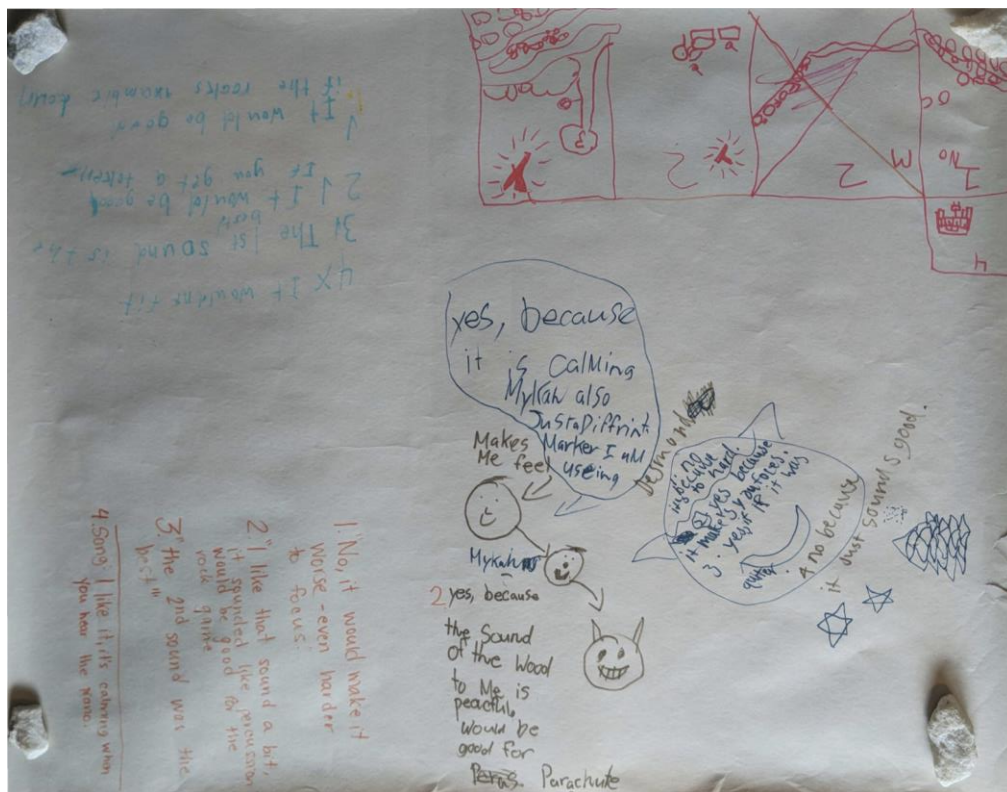


Figure 7. An example of children’s written notes from Session 3.

3.6.5. Researcher's Written Notes

Following each session, I made note of my own observations. These were short and focused on what worked well, challenges I experienced, and any follow-up needed prior to the next session. These served as a reminder related to findings related RQ 1 and RQ 2. I also received brief written notes from an SFU researcher after Session 2 since they were unable to stay for the debrief. These summarized a table group's work for the day and helped me understand their group's notes. It did not directly contribute to answering RQ 1 or RQ 2. I invited school staff to submit feedback forms each session. Unfortunately, the staff did not complete them, and they are therefore not considered part of the evaluation. While this information would have been valuable, out of consideration for educator workloads I did not press school staff for their return.

3.6.6. Audio Recording of Interview with Teacher

After completing the co-design sessions, I returned to the school the following week to meet with the classroom teacher for an interview during her lunchbreak. The other school staff were not available. I asked a series of open-ended questions (Appendix C). These were to get a better understanding of how the children behaved during co-design activities, and whether their contributions were out of the ordinary from their normal classroom behaviour. This helped me respond to RQ 1. I also asked for their feedback on possible areas of improvement. Teachers are experts at working with children, and this was helpful to better understand how future research studies could be made better.

3.7. Data Analysis

3.7.1. Audio Recordings of Sessions

Between sessions I listened to the recordings and took notes on children's ideas related to Mind-Full Wind. Following the study, I manually transcribed the recordings using oTranscribe¹¹. Another SFU graduate student reviewed portions of the transcription to ensure accuracy. Recordings were all of conversations involving multiple

¹¹ <https://otranscribe.com/>

people. I attempted to identify each student's contribution to the conversation. This helped ensure the structure of the dialogue was maintained even in written text. In the data, children's anonymity was maintained by using pseudonyms. Occasionally it was impossible to identify which child was speaking. This typically occurred because multiple children were speaking at once, or because two members in a conversation had similar voices. In the transcription, I identify these statements simply as "Student." Due to the close proximity of groups to each other, and some children's tendency to speak very quietly there are times in the recordings when children's statements are indecipherable. These statements are labelled "inaudible" in the transcript.

Unfortunately, one table's audio recording data was lost in Session 2 because the device was turned off early in the co-design task. This may affect the reliability of the data. However, I was able to review children's written notes for their main ideas. In Session 4, the class was in a small room, and all the groups were sitting so close to each other the recordings were indistinguishable. This should not affect the results as I was able to parse out the conversations taking place.

As discussed, co-design research with children is relatively new, and the field exhibits great variety of methodological approaches. I was unable to find examples of coding strategies for my specific use case. As such, I decided not to define a coding dictionary before starting analysis. I followed an inductive approach motivated by grounded theory. My coding categories emerged as I progressed with the analysis. I started at the level of each utterance¹². I reviewed the transcripts for accuracy. I identified errors in transcriptions and verified those against the audio records. I identified ambiguous or confusing statements, and verified these against audio and video records. Next, I read each utterance for coding. At this stage, I had multiple utterances for each child. I analyzed transcriptions while looking for themes in children's responses. I searched for ideas related to RQ 1, how children can contribute to co-design, such as using objects to create sounds in the environment. I did the same for RQ 2, searching for ideas related to specific sound ideas. Next, I re-analyzed the data looking for other themes related to co-design and Mind-Full. I completed all the coding using NVivo software, and a second researcher reviewed sections to verify the codes.

¹² I define an utterance as a contiguous group of words and sounds spoken by each participant at a distinct moment in time.

Once I had coded the data, I looked for overarching keywords that represented concepts—for example, the code “wind sounds”, includes statements about “blowing,” and “breeze”. It also includes instances in the transcription when children imitated the sound of wind with their breath. Next, I reviewed the concepts and clustered them into overarching themes. Finally, I used the statistical programming language R to run basic text analysis on the corpus. I measured word use frequency, sentiment and the ratio of individuals speaking per each session.

3.7.2. Audio Recordings of Researcher Debriefs

Between sessions I listened to the recordings of the researcher debriefs and took notes. I paid attention for any necessary changes that needed to be made to the methodological design in order to implement them in time for the subsequent session. Following the study, I listened to the recordings again and transcribed them. I reviewed the transcriptions again for accuracy. I then analyzed the transcriptions, looking for statements related to the themes identified in my review of the audio recordings of the sessions, as well as any new themes. Following the study, I checked in with other researchers to confirm there was no additional information or context I was missing. By incorporating other researcher’s observations, I sought to improve the validity of my findings through triangulation.

3.7.3. Video Recordings of Sessions

Following the study, I watched the videos of the session to remind myself of what took place. I also looked for interesting behaviour I may have missed while running the study, as well as moments that other researchers had mentioned during our debriefs. This helped me better understand what had happened during the session. No further data analysis was done on the video. However, I often referred to it while transcribing audio tracks to verify which child was speaking, or to clarify the context of the discussion. For example, one child was heard asking about something unidentified in the recording, by reviewing the video at that time point, it is clear she is pointing to the recording device on the table. I did not sync the audio and video files; however, it is easy to find specific time points in the recordings relative to the start of each session.

3.7.4. Written Notes from Table Activities

Children's notes were reviewed every week during the study for ideas related to Mind-Full Wind. The paper copies were digitized, the text transcribed, and drawings annotated. Based on the ideas identified in the notes from the co-design sessions, I compiled sound ideas to bring to the class for evaluation. For Session 2, I reviewed this content, looking for words that appeared most frequently among the different table groups. Written notes from table activities helped triangulate the audio recording data because they typically contained ideas that the children thought were most worthwhile noting or drawing out, improving the validity of the work. For Sessions 3 and 4, evaluation of sounds was completed based on children's sound preferences as evidenced by their written notes.

Following the study, I coded the notes and grouped findings into themes using the same coding practices applied to the audio recordings. For example, words like "blowing," "breeze," and "rustling grass" were grouped into the overarching theme "Wind."

3.7.5. Researcher's Written Notes

I reviewed my own written notes prior to each session to ensure I had made all required changes to the day's scheduled activities. Following the study, I once again reviewed my notes. I analyzed this data looking for themes related to those identified in the analysis of the recorded audio, as well as any interesting observations, or emergent themes relevant to my study.

3.7.6. Audio Recording of Interview with Teacher

I twice listened to the interview recording and then transcribed it. I reviewed the teachers' responses, looking for themes related to those identified in the analysis of the recorded audio, as well as any interesting observations, or emergent themes relevant to my study.

3.8. Known Limitations

In this section, I outline potential limitations to my methodological design based on my review of the literature. Where possible, I also identify the efforts I made to address these possible issues.

3.8.1. Working Within a School Environment

Overall, running this study in a school was tremendously beneficial. I could work with a group of children who were the right age, and who had experience with design. The environment was familiar, school staff were available to support the activities, and there was space and equipment available. There were, however, a few expected drawbacks. Based on my review of the literature these included: less input into scheduling; little control over the number of participants; and power imbalance between school staff and children.

Less Input into Scheduling

Working within a classroom meant I had little control over scheduling co-design sessions. The content of my work overlapped with two specific units in the design class—one on sound, and one on cause and effect. The co-design sessions had to take place during the time scheduled for these units in the semester. I made arrangements to hold weekly sessions with a break in between for the winter holidays. While the amount of time between sessions is in line with my proposal of “minimum 1 week” identified in **Guideline 3**, it proved to still be very a short amount of time to review all the data. I addressed this by attempting to prepare as much material in advance as possible.

No Control Over the Number of Participants

When working in a classroom setting one must work with all the students in the class. Large groups can be challenging in co-design, particularly with young participants who may require additional guidance. It also may become challenging for children to see their work represented in larger groups. In this co-design activity, I was prepared to work with as many as 19 children. This is a larger group than would be ideal; however, based on the literature review, I knew it was possible so long as there were enough adults to break into smaller groups (as per **Guideline 4**). I strove to find as many SFU

researchers as possible and supplemented the gaps with school staff. Since there were still too few adults to have two at each table group (one for facilitating, and one for notetaking), I arranged for audio recording devices at each table to capture the conversation.

Power Imbalance Between Teachers and Students

As per **Guideline 5**, I recognized the inherent power imbalance between school staff and students. During co-design exercises, adults ideally work alongside children as equals in the design process. Although little can be done to eliminate this dynamic in a school setting, I met with school staff in advance of the study to explain the role of adults as design partners and shared the recommendations from **Guideline 5** to minimize this risk.

3.8.2. Performing for Recorders

Previous research on co-design noted that children may behave differently when they are being recorded (Druin, 1999). Ideally, in our study there would be enough adults that recording devices would not be needed. However, in the absence of this, I had to rely on audio and video recording data. I attempted to reduce the distraction by keeping audio recorders on the tables to one side and placing the video cameras in unobtrusive locations. While I expect children may behave somewhat differently with recording devices present, I do not believe this had a significant impact on the study's findings.

3.8.3. Designing Sound with Words

A unique limitation of this study is the nature of the design task itself. I asked children to design sounds using verbal descriptions and sounds, written words, and pictures. Due to the size of the class and the close neighbouring classrooms, I was unable to provide noisemakers and instruments with which children could play and experiment.

3.8.4. Assessing Validity and Reliability

Assessing validity is a known challenge in co-design. Previous researchers have addressed this by gathering data from multiple sources and triangulating research

findings. In this work, I do this by gathering recordings of co-design sessions, children's written notes, and researcher observations. I addressed discrepancies between data sources by comparing them in context (e.g., looking to the audio recording of a conversation to provide an explanation as to why a child wrote an unexpected idea down on the paper). I also asked another researcher for their insight on sections of the data.

Assessing reliability in co-design is also difficult. People's preferences are subjective. It is certainly possible that running this study with another group of children would yield different conclusions.

Chapter 4. Results

In the following section I describe my findings from this co-design study. First, I respond to RQ 1 by outlining the different ways I observed children can contribute to the co-design process, i.e., *ideation, clarification and elaboration*, and *evaluation*. I extend this by also identifying the aspects of co-design that children appeared to struggle with during this research study. Next, I respond to RQ 2, summarizing the sounds suggested by children for Mind-Full Wind, and describing how these ideas developed throughout the course of the study. Finally, I conclude with notes related to the research methodology of each session which may be of use to future researchers interested in running co-design studies.

4.1. RQ 1

In what ways can children contribute to co-design for developing sounds for a neurofeedback system?

The addition of sound to Mind-Full has the potential to improve children's experiences while using the game to learn self-regulation. Game sound may enable users to benefit from multimodal feedback and improve feelings of immersion in noisy school environments. However, before one can further explore and validate the potential advantages of including game sound, it is necessary to first design and add appropriate sounds to the system. I found little guidance in the literature on designing sound for neurofeedback games for children, and as an adult researcher I cannot assume to know what sounds might appeal to young users. For this reason, I look to children to help guide the development and evaluation of game sounds for Mind-Full. However, there are few examples of co-designing sound for tablet games in the literature, and there remain questions about the ways in which children can contribute to this type of work.

In my analysis of the data, I found evidence of children contributing to the co-design of sound in the following ways: first, they took part in the ideation and brainstorming of new sounds for the game; next, they clarified their preferences, and elaborated on previous suggestions; finally, they evaluated potential sound designs. Nonetheless, based on my analysis, there were aspects of co-design that were

challenging for children, specifically staying on task and understanding constraints on abstract activities. I provide more details on these findings below.

4.1.1. Children Can Take Part in Ideation

In my analysis of the audio recordings, video recordings, and children's written notes, I found evidence of children proposing new, unique sound ideas for Mind-Full Wind. Children expressed their ideas in a variety of ways. In audio recordings, I observed children articulating their ideas using words, for example, in Session 1 Kenneth can be heard stating "bird chirping sounds," meanwhile at another table Susan proposed "splashes of the water."

In the audio recordings, I also heard children expressing sounds ideas using their voices and mouths, for example in Session 1 Emily is heard making a loud, crackly blowing sound by breathing through her pursed lips to imitate heavy wind.

In researcher observations and video recordings, I found children not only used words to describe sounds, they also use their bodies to imitate and express sounds. For example, in Session 2, Cory knocked on the table with his fist to imitate the sound of a rock hitting the ground.

Finally, in reviewing children's written notes, I observed children expressing ideas using words and drawings, for example, in Session 2, Phil drew a picture of a violin to indicate a type of instrument he thought would go well with the Mind-Full Wind pinwheel game (Figure 8). On the same sheet of paper, Brandon wrote the word "rocks" in reference to the stone game.



Figure 8. Drawing of a violin from Session 2 children's notes

In my analysis of the audio recordings I found evidence that children often required prompts or encouragement from adult facilitators to participate in the idea generating process. Teachers and school staff were particularly adept at this because of their longstanding relationship with children. I observed teachers and school staff using their pre-existing knowledge of the children to motivate them. For example, the classroom teacher Ms. Shaw could be heard connecting the activity to a student, Jason's, interest in video games:

Ms. Shaw: "I was just wondering if you knew what kind of music they have in MineCraft."

Jason: "They don't even barely have music in games."

Ms. Shaw: "Well there is always the music playing in the background."

Another example can be heard when Brandon was struggling to come up with ideas for relaxing. Ms. Shaw reminded him of an interaction she had seen earlier, saying "well I know this morning when you were a little upset you liked being with your mom, so does the sound of your mum's voice help you?" In this way, "leading questions" helped to keep children engaged in ideation.

4.1.2. Children Can Clarify and Elaborate on Their Ideas

In my analysis of the audio recordings, video recordings, and children's written notes, I found evidence that children can clarify and elaborate on their ideas. Adult facilitators also play an important role in encouraging this by asking children probing questions. When children are heard in recordings making vague or unclear statements, I frequently observed adults asking them to clarify or to add more detail to their suggestion. For example, in Session 1 Ms. Barlow asked Julia to provide more information on her suggestion of wind blowing:

Julia: "Oh I know, the sound of wind blowing."

Ms. Barlow: "Would you say it's a whistling wind or just wind?"

Julia: "Whistling wind."

This additional descriptive information was valuable when searching for sound samples prior to the third and fourth sessions. I found evidence of children elaborating on each other's ideas, as well as their own. For example, in Session 2 at Ms. Barlow's table, Kenneth suggested using the sound of rain in the paraglider game. Other children at the table then began imitating rain sounds with their mouths, tapping their fingers on the table, and providing additional descriptive words, for example "like rain pitter patter." In this way children influenced each other's suggestions.

In my analysis of the audio recordings, I found evidence suggesting that with encouragement from teachers, children can identify qualities of sounds that could be changed to provide feedback to users. Some children used words to express these qualities, while others imitated what they would sound like. For example, in Session 2, when asked how her sound idea could change as a user becomes more relaxed, Emma imitated the sound of a bird chirping starting from a high pitch to low pitch. In my analysis of the video recordings and researcher observations, I also noted one child expressing sound changes using their body; while describing a sound using words, Milo simultaneously articulated the change in volume by moving his arms from close to his chest (small = quiet), to wide and outstretched (large = loud).

4.1.3. Children Can Evaluate Proposed Ideas

Evaluation is a critical stage in the co-design process. It is not enough to ask for children's ideas, they should be involved throughout the design process. In my analysis of the audio recordings, video recordings, children's written notes, and researcher observations, I found evidence that children can participate in the evaluation of sound ideas.

The co-design activities in Sessions 3, 4 and 5 involved evaluation activities. In Sessions 3 and 4, children listened to sound samples and shared feedback verbally and in written notes. For example, after listening to a recording of a bird call, Fred can be heard stating "I don't know, it wouldn't fit," while Mary said "its too squawky." Children then marked down on a piece of paper if they liked the sound using symbols, for example checkmarks or happy faces. After listening to each collection of sound samples based on themes, children reported verbally which they liked best for the app and why. For example, after indicating that the third sound sample was her favourite bird sound, Anne stated "its nice, it was much more better than the rest." This was helpful in determining which sounds should be included in the final design.

In the final session, children evaluated a prototype of the enhanced Mind-Full system. First, as a class by responding to a short series of open-ended questions about the game, and also in one-on-one interviews a researcher had with two children who had an opportunity to play the game with sound themselves.

4.1.4. Children Have Trouble Staying on Task

As one might expect when working with this age group, some children appeared to have trouble staying on task. While this was not surprising, it serves as an excellent reminder of the important role adult facilitators play in the co-design process. Not only do adults take part in contributing to the design, they are also critical to ensuring children do not lose focus. My analysis of the data showed evidence of teachers frequently reminding children of the research goals and the children's role in co-design. For example, in Session 1 when Andrew started being silly, Ms. Williams said to him "remember this data is going to go back to the researchers," to keep him focused. During that same session, Ms. Shaw sent Brandon away from the classroom for a few minutes

because he was distracting his tablemates. Following Session 3, we received feedback from the classroom teacher that sixty-minute sessions were too long for many children of this age to remain focused.

4.1.5. Children Have Difficulty Understanding Constraints on Abstract Activities

In my analysis of the audio recordings, I find evidence that some of the participants were confused at times by the abstract nature of some of the design tasks. For example, children did not always limit their suggestions to the constraint of designing sounds. Children can be heard in the recordings suggesting smells and other ideas that were not sound related. For example, in Session 1, Jason suggested “the smoke of dynamite.”

Beyond this, during the sound evaluations in Sessions 3 and 4, some children had trouble expressing whether they liked a sound because they found it interesting (or enjoyable), or whether they specifically liked it for the Mind-Full application. Adult facilitators helped clarify children’s preferences by frequently reminding them of the design goals and constraints. For example, in Session 3 after Aiden identified a sound that he liked, Ms. Williams checked whether it was his preferred sound for the context of playing Mind-Full:

Aiden: “I liked the second one the best.”

Ms. Williams: “you liked the second one the best? Why? And would you say you liked it the best for relaxing, or you just like the sound?”

Aiden: “I just liked the sound.”

Ms. Williams: “For relaxing?”

Aiden: “No its not relaxing.”

In this way, teachers helped to ensure validity in children’s sound evaluations.

4.2. RQ 2

What sounds do children suggest for the Mind-Full Wind neurofeedback system?

The class came up with the following sounds ideas for Mind-Full Wind: for the pinwheel game, a breezy wind sound that gets louder as the user becomes more relaxed, and quieter when they are no longer relaxed; for the paraglider game, a chirping bird sound that gets busier (with more bird sounds added), as the user becomes more relaxed, and less busy (bird sounds removed), when the user stops relaxing; for the stone game, a sound of clunking rocks, which can be heard when the rocks fall in hit the ground in the game animation triggered by focusing. These ideas were developed over the course of five co-design sessions.

In Session 1, children came up with sounds for all the Mind-Full games. Based on my analysis of recorded audio and written notes, when grouped by theme, children came up with nine unique sound ideas for Mind-Full Wind. The most frequently mentioned theme was “wind sounds,” which appeared eight times in children group notes, and included suggestions such as “blowing,” “rustling grass,” and “whistling wind.” Other sound ideas proposed, and verbally supported by multiple children, included “bird sounds,” “water sounds,” “stone sounds,” “silence,” and “music.” Through my analysis of the recorded audio I found evidence that suggests that children who proposed music preferred music that is “calm” and does not include lyrics. According to one child in the class, Julia, this is because “you would want to try to hear the words and sing them and then imagine that. Then you will have that in your head and then you won't be able to focus.” This sentiment was echoed repeatedly by other children during this session.

In Session 2, children had second opportunity to suggest sounds specifically for Mind-Full Wind. They were given this opportunity, because several of the groups did not have time to look at all three Mind-Full Wind games (pinwheel, paraglider, stone) in the previous session. In my analysis of the audio recordings and children's written notes, I found evidence that, based on the number of unique children who proposed an idea, the most popular themes among the class were wind sounds for the pinwheel game, bird sounds for the paraglider game, and the sound of rocks for the stone game. Water sounds were also frequently referenced sounds by children when discussing both the

pinwheel (Figure 9) and stone games. I used these sound ideas as a guide when gathering samples to bring to the class for the following session. In addition to this, children also described the types of feedback they thought would suit these games. Based on my analysis of the data, the most commonly cited types of feedback for wind sounds, bird sounds, and stone sounds were: a wind that grows louder as the user relaxes; bird sounds that gets busier as a user relaxes; and stone sounds that make a tumbling sound when the rocks in the game animation fall to the ground.

In Session 3, I brought in sound samples gathered based on children's ideas from the previous session. For the pinwheel game, the children indicated a preference for the second wind sound (the sound of a gentle breeze) and a water sound. Of the 12 children taking part in the evaluation (two at a time were outside of the room playing Mind-Full), nine indicated in their written notes that they liked the second wind sound, and nine indicated they liked the water sound for the game. The other two sound examples for the pinwheel game were not nearly as popular, with less than half the children indicating that they liked them. After hearing all the sound examples, multiple children suggested that the water sound seemed like it would be a better fit for the stone game. I asked the class if we should consider using the water sample with the stone game instead, several children agreed, and none objected. Therefore, I incorporated the second wind sound into the app, and added the water sound to the list of sounds to be reviewed the following session when we evaluated sounds for the stone game. Next, for the paraglider game, children indicated a strong preference for the third bird sound (a small bird chirping sound). This was described as "smooth" and "peaceful" by children in their written notes. Only two of the 12 children did not like this particular sound, these children indicate it was "because it was too loud" and "because it is annoying." Since it was the most well-liked of the sound samples, I incorporated the third bird sound into the app.

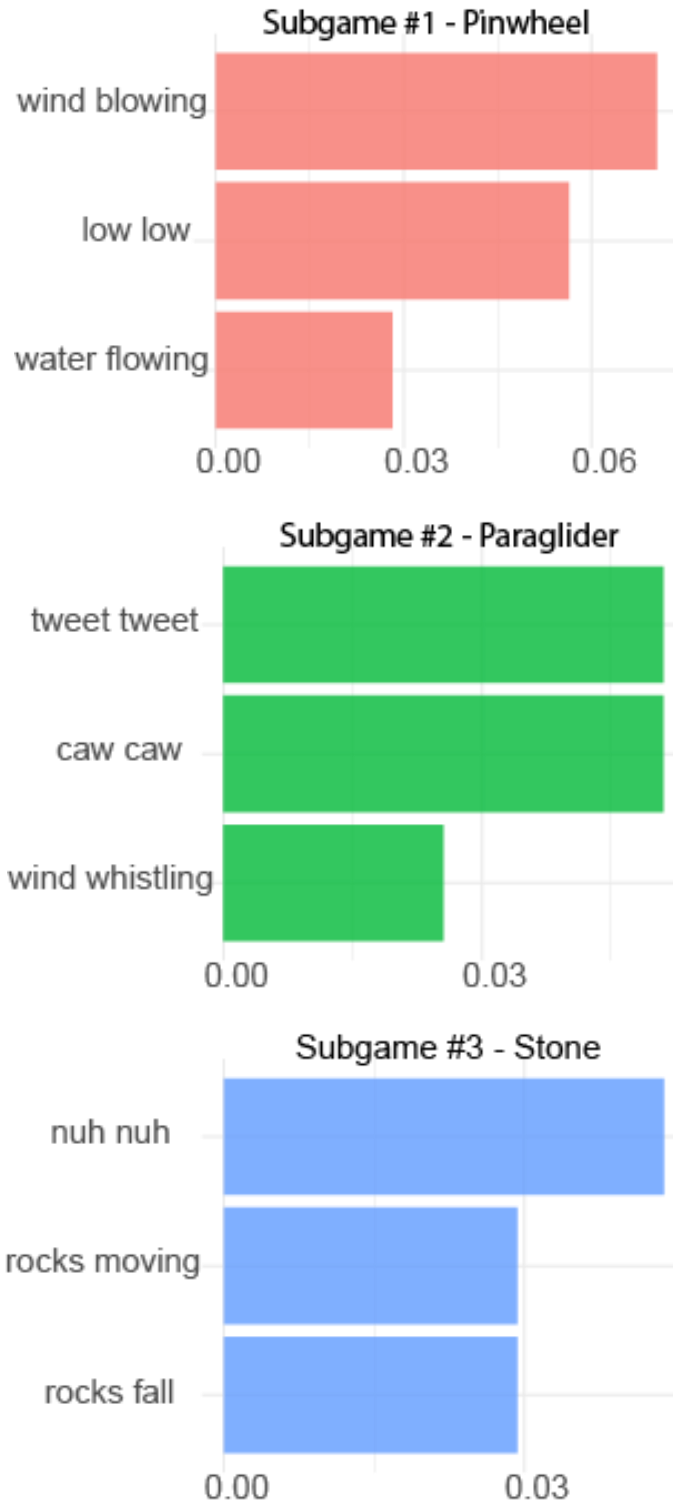


Figure 9. Most important terms by subgame (pinwheel, paraglider, stone), top 3 bigrams spoken by children. Horizontal axis is document frequency weighted by Term Frequency-Inverse Document Frequency (TF-IDF).

In my analysis of the audio recordings and written notes from Session 3, I find evidence that the children did not like the music selections I brought to this class. For example, when I played one sample the whole class went “noooo” in unison in response to it. One of the other sound samples was a classical song, as per many children’s recommendations from Sessions 1 and 2; however, the children responded with unfavorable comments such as:

Julia: “I don’t know, it just sounds like two people are falling in love.”

Emma: “eww, it’s gross.”

When I played a jazz song, as per many children’s recommendations from Session 1 and 2, children responded with:

Cory: “too old.”

Milo: “too old.”

Mary: “very weird.”

Anne: “no this is an old man.”

Brandon: “it’s an old man.”

Cory: “weird interesting, very not cool.”

Mary: “not a good song.”

Over half the children in the class indicated in their written notes they did not like the selections presented. Based on children’s reactions, I decided to seek out different musical examples to show them the following week.

In Session 4, the co-design activity was similar to Session 3. Based on my analysis of the audio recordings and children written notes, the most popular sound sample was the second example (the sound of a small number of rocks gently knocking each other). Only one child did not believe it would be a good fit for the app. Children’s written notes indicate that children liked the sound, for example children wrote “it makes you focus,” “just right yes,” and “yes it makes me pay attention because of the clanging.” This week’s music example was better received than the previous week’s examples. In written notes, only three children did not believe it would be a good fit for the app. It was described by one of the children as “calming.” In Session 4, I also asked for feedback on

a mock-up of the game that incorporated the previous week's bird and wind sounds. Based on my analysis of the data, the children accepted the prototype. When asked what they thought, the children had positive feedback, for example Emma said "I really liked the bird sounds," and Julia said "I like how its calming." No children objected to the sound design.

In Session 5 children provided their final thoughts on the prototype. Based on my analysis of the audio recordings from the groups' open ended question session it is not clear that children all agreed on the final design; however, most of children's feedback identified parts that they liked, for example, Milo said "I like the first one," and Emma said "I like the last one". Based on my analysis of the audio recordings of the one-on-one interview sessions with the children who tested the game, the children appeared to generally agree with the sound design. The children wore headphones while testing the app. Both Milo and Phil said they thought the new sounds were "good." When asked to clarify, Milo responded "I liked that it, like, for the paraglider game, I liked that it had so if you were focused, the bird tweets would get more frequent, but if you got less focused it would stop." When the researcher asked Phil to clarify, he responded "It's like very calm. So you can relax with it."

Both children reported that the sounds made them feel more calm. However, it is unclear if it made them feel any more attentive. When asked if they preferred playing the game with sound or silence, both children suggested they preferred it with sound. When asked if they preferred to play the game with a combination of sound and music, just music, or just sound, Milo and Phil both agreed they preferred just sound with no music. Based on their feedback I removed the music from the version of Mind-Full with sound. These sounds would allow a child to play without visual feedback. It is unclear how these findings differ from what adult developers may have created if children were not involved in the design process.

4.3. Research Methodology Observations

As an emerging technique, co-design's progress is cumulative. My research design was informed by the literature, and by the specific guidelines I compiled based on previous research. In the interest of further methodological development, in the following section I outline findings related to this co-design study's research methodology. I review

observations I made based on my analysis of the data, broken down by each research session. I conclude with a few overarching findings. These observations will hopefully help future co-design and neurofeedback researchers as they adapt and build on my design.

4.3.1. Session 1

The goal of Session 1 was to introduce the children to the Mind-Full games and the design task. In this co-design session, children successfully began the process of devising sound ideas for Mind-Full; however, based on my review of the written notes, I find evidence that none of the table groups had time to complete the activity for all nine Mind-Full Wind games.

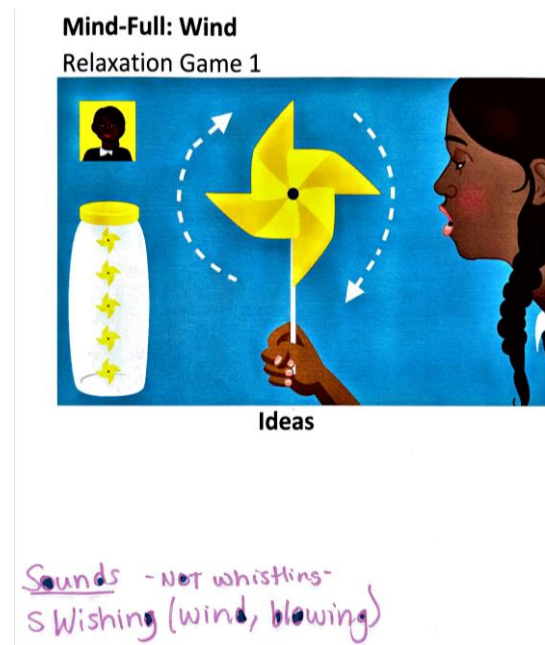


Figure 10. Children’s written ideas for Mind-Full Wind pinwheel game from Session 1.

In my analysis of the audio recordings from the study’s introduction in Session 1, I find evidence that children were curious about the app. For example, many children asked questions about Brain-Computer Interface technology such as:

Emma: “Will it feel a little bit like virtual reality?”

Phil: “Is it going to absorb your brain and see how smart you are or something?”

Other children had questions about Mind-Full games, for example:

Milo: "In the game, if you think about what to do, will it actually happen?"

Fred: "What happens if you imagine it going this way?"

Aiden: "Why is there like different apps for different types of people?"

Other children had questions related to how long it took to build, and why there were multiple types of headsets.

In my review of the data, I find evidence that many children appeared interested in trying the game, based on how quickly children volunteered to be the first to try it. As children played, their table groups can be seen in video recordings gathered around these watching them use the tablet. At one point a child using the game, Brandon, appeared to have trouble focusing due to the children crowded around him, and can be heard "shushing" the children next to him.

In audio recordings, children can be heard questioning some of the Mind-Full games' imagery; for example, several children were unsure if the background of the stone game was water or grass. Another student, Fred, suggested that the imagery in Mind-Full Sky, did not seem calming to him:

Fred: "Oh a dead fish, um, this is not calming"

Ms. Barlow: "Now that's an interesting thing to say"

Cory: "That would make me scared"

Ms. Barlow: "What do you see here?"

Fred: "Well I see a dead fish. See the crow, just having a dead fish for breakfast? There is two dead fishes, and I don't think that's calming."

This was interesting because this particular game was developed in collaboration with an Indigenous community, who may respond differently to this type of image.

Although I tested the equipment in advance, the headsets did not work when multiple units were operated at the same time due to Bluetooth interference. Researcher notes reveal that only five of the 16 children were able to successfully use the system during Session 1. Further, as evidenced by researcher notes, these technical challenges

caused stress for some children, which may have been made worse by the close attention of their peers. For example, one student, Susan, was observed by a researcher becoming visibly upset after not being able to get the relaxation game working. This was discussed in the researcher debrief following this session.

Two members of the research team noted in the post-session interview that it can be challenging to troubleshoot the BCI headsets on children they had never worked with before. NeuroSky headsets must be secured on a child's forehead in order for the sensors to make a good connection. Researchers reported this was awkward since they did not know the children well. Following Session 1, the other researchers and I discussed how to move forward with having children try the app. It was determined that we could have two children practicing at a time, using two different models of the headset in a neighbouring classroom for future sessions. We could continue this until all the children had a chance to play.

Based on my analysis of the data, in this session children took part in ideation, clarification and elaboration of sound ideas. The children proposed the following sounds for Mind-Full Wind, "wind sounds," "bird sounds," "water sounds," "stone sounds," "silence," and "music."

4.3.2. Session 2

The goal of Session 2 was to introduce how game sound can convey information and extend children previous' work developing sound ideas for Mind-Full by identifying ways in which they could change to provide feedback to users.

This session took place right before the school's winter holiday. Based on researcher's observations, as well as audio recordings of the session, I find evidence that children were very affected by the time of year. For example, in the audio recordings, one child was heard recommending sounds to Ms. Shaw that appeared to relate more to the season than the Mind-Full games.

Ms Shaw: "great, lets unpack that. calm music would be, classical music? What would you like in this one, he is in the air, do you want some Beethoven? Do you want violins?"

Emily: "Snow falling music, like Christmas music"

An unusually heavy snowfall began midway through the class. Based on my analysis of the recordings, once the children became aware of the snow, they lost focus and were no longer coming up with suggestions for the game.

Some of this session's data was lost unfortunately, due to a recording device being turned off at the start of the session. However, the group's main ideas were captured in their written notes. This loss reduces the validity of the work, but the impact is minimized because I was working with this particular group during this session, and as a result was able to recall much of the discussion around their written notes.

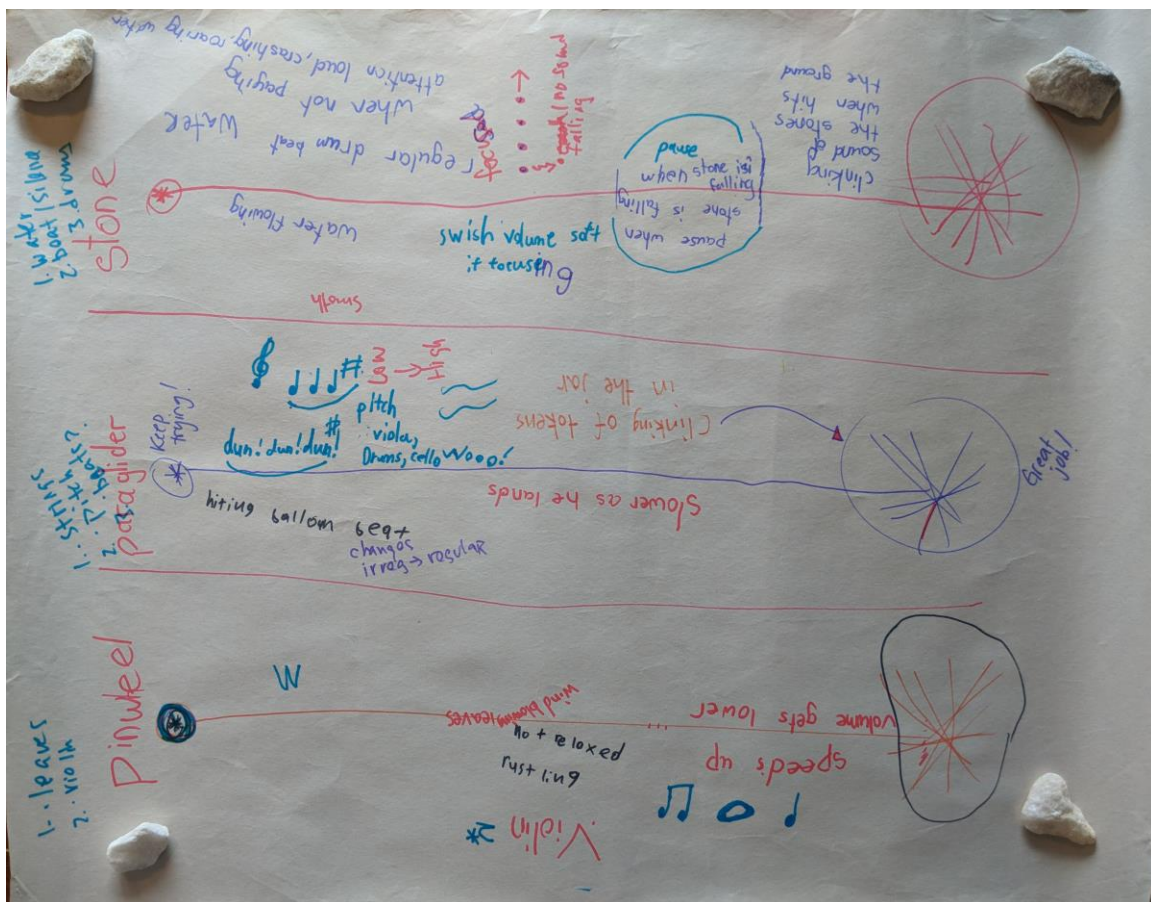


Figure 11. An example of children's written notes from Session 2.

While the co-design activity was taking place, one SFU researcher worked with children one-on-one in the neighbouring classroom. Based on my analysis of the debrief with the researchers at the end of the session, I find evidence that this strategy was successful for enabling children to use the application themselves. The researcher reported "it was really interesting because no one was struggling, and maybe that was

because they were a separate room. The last two girls who were in there were really good at the relaxation one and then like you can see them shift and have to focus to do the focus one.” This method of working with just a few children at a time was an improvement over the previous’ weeks’ strategy.

Based on my analysis of the data, in this session children took part in ideation, clarification and elaboration of sound ideas. The most popular themes among the class were wind sounds for the pinwheel game, bird sounds for the paraglider game, and the sound of rocks for the stone game. Water sounds were also among the most frequently referenced sounds by children when discussing both the pinwheel and stone games. In the data, the most commonly cited types of feedback for wind sounds, bird sounds, and stone sounds respectively were: wind that grows louder as the user relaxes, bird sounds that gets busier as a user relaxes, and stone sounds that make a tumbling sound when the rocks in the game animation land.

4.3.3. Session 3

The goal of Session 3 was for children to evaluate potential sound treatments gathered based on their ideas from Session 2. In preparation for this week’s session I found it challenging to find audio resources. Although there was a longer break than usual between sessions (three weeks), there was a significant amount of data to review, in addition to preparation tasks for the final three sessions. I found it particularly challenging to find creative commons music that met the children’s broad definitions, as well as creative commons sound samples that were of appropriate quality to be able to remix to match children’s ideas for feedback.

The configuration of the classroom in this session was not ideal for children to be able to hear the sounds. Some children were much further away from the speakers due to the location of the tables. Based on my analysis of the data, I find evidence that children had trouble with the volume of the sound samples during this session. The volume had to be louder for children in the back to hear (although I had to be careful not to disturb neighbouring classes). An unidentified child sitting near the front of the class can be heard saying “too loud,” when evaluating a sound, another child Jason at the same table group, can be heard saying “can I say yes if it was a bit quieter?”

Based on my analysis of the data, in this session children took part in the evaluation of sound ideas. The results of this co-design session indicated that children's preference for the second wind sound (a gentle breeze) for the pinwheel game, and the third bird sound (chirping) for the paraglider game. Based on children's suggestions, I would add the water sound to the following week's review process for the stone game, and I would revisit potential music ideas because the children did not appear to like the ones I brought for their consideration.

4.3.4. Session 4

The goal of Session 4 was to show children a prototype of the system, gather additional feedback on sound ideas, and brainstorm techniques for how to evaluate the game. Based on my analysis of the audio recordings, there were fewer issues with the volume of the sound samples in this session. In the researcher debrief at the end of the session, the other SFU researchers confirmed that all the children had successfully tried using the Mind-Full app.

Based on my analysis of the data, in this session children took part in evaluation of sound ideas. The results indicated that children preferred the second rock sound (a sound of a small number of rocks gently knocking each other) for the stone game. Since the children seemed to agree with the music sample I demonstrated, I recorded a simple version of a melody using the same harmonic principals to incorporate into the game and sought children's feedback in the final session.

4.3.5. Session 5

The goal of the final session was to present the enhanced version of Mind-Full, debrief with the class about the co-design process, and gather feedback from selected children. Based on my analysis of the audio recordings, the children report that they can see how they helped to build the game, although when asked to elaborate, children's responses were vague, for example when asked in what ways they can see their contribution, Kenneth responded "The different cool sounds." I asked the children if they thought the game was better with or without sound and the children who responded all identified that they preferred the game with sound.

Although the final activity, in which children designed their own neurofeedback game, was not part of the sound co-design process, based on my analysis of video and children's notes, I found evidence that children are able to come up with their own original neurofeedback game ideas and several children's included ideas for sounds as well.

Overarching Observations

As anticipated in our research methodology, I found evidence to suggest children often acknowledge the presence of recording devices. Many could be heard "performing" for the recording device at the start of the co-design sessions, for example, speaking into it using a funny voice or making jokes about it recording them. The devices were also frequently touched by children, making it difficult to hear the voices of children at the table. I tried to address this in later sessions by placing recorders away from the center of the group and using tablets that could be locked in recording mode.

Following the study, I ran simple text analysis on the transcribed data from the co-design sessions. In figure 12, I include the results of a sentiment analysis of utterances by session of researchers, children, and teachers. The horizontal axis includes the number of minutes. I group utterances into two-minute intervals. Co-design activities range from approximately 20 to 40 minutes. The vertical axis shows the net number of positive words spoken every two minutes. These terms are drawn from a predefined dictionary (in this case, the Bing sentiment dictionary (Liu, 2012)). For example, positive words include "kind" "happy" and "beautiful". Negative words include "bad" "death" and "unhappy". While children are observed using a mix of positive and negative words, researchers and teachers use almost exclusively positively coded language. This reinforces my observation that teachers provide encouragement and support to children.

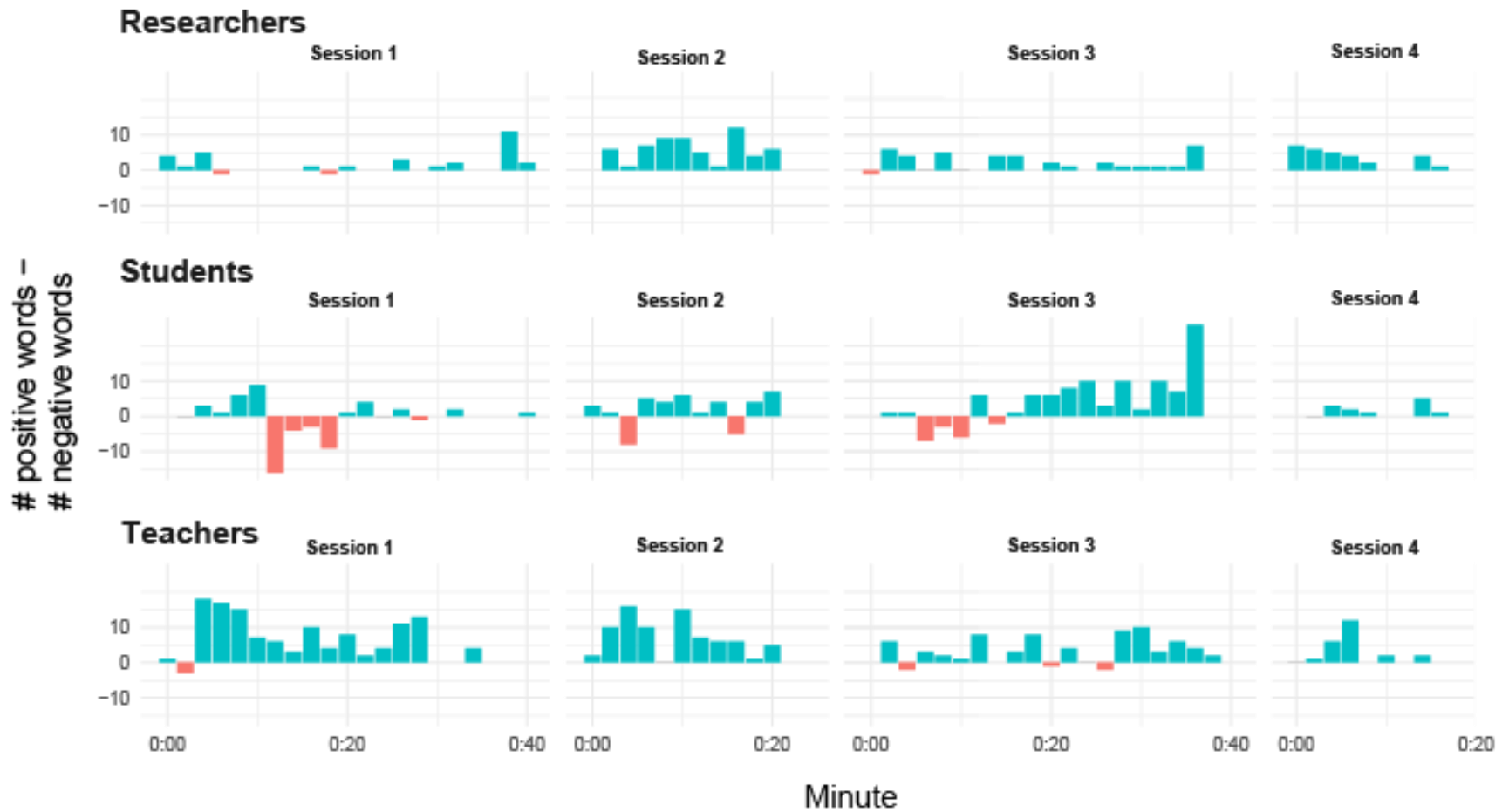


Figure 12. Sentiment by session, net number of positive words every two minutes.

I also ran an analysis to explore the percentage of utterances spoken by three different groups: teachers, children, and researchers (Figure 13). I note that teachers did a lot more speaking relative to researchers and children in the first and second sessions compared to the third and fourth sessions. As suggested by the teacher, the increased contribution of children in Session 3 relates to an important fact about co-design with this age group: Children are better at giving feedback on specific examples than on abstract concepts. I believe the relative decrease in talking in Session 4 is due to the change in location. During Sessions 1-3, the class was in larger rooms with multiple tables. In Session 4, the class was in a small room with no tables. Teachers could not work with children as much to encourage them. This led to reduced feedback from the children.

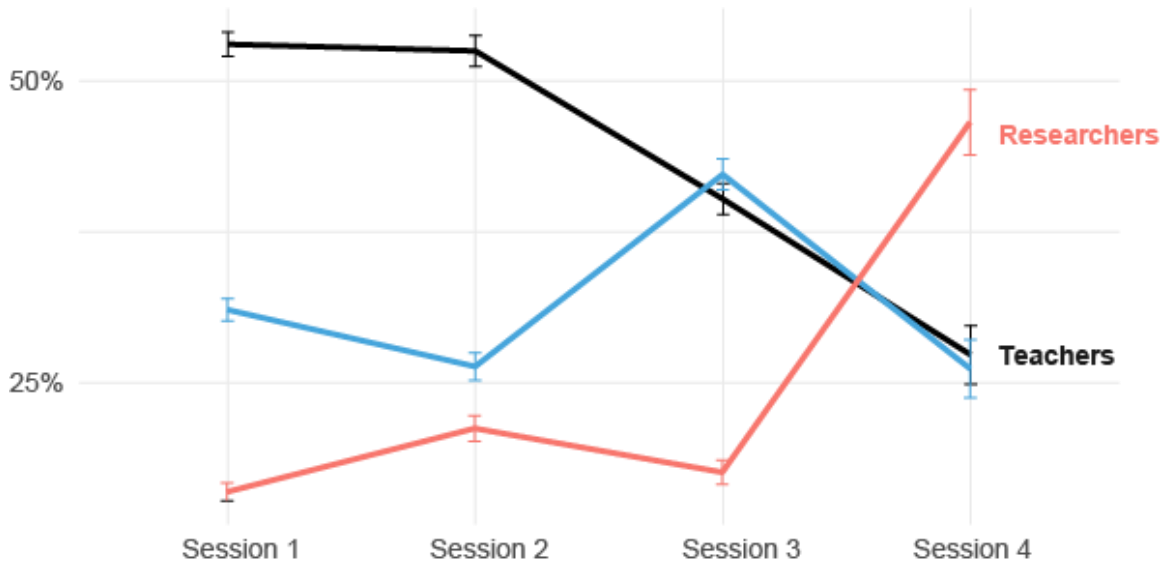


Figure 13. Percentage of discussion by each group during co-design sessions, 95% confidence interval.

Chapter 5. Discussion and Design Implications

In the following section I provide a detailed discussion of my results. I begin by relating main findings back to related work in the co-design literature. I identify strengths of this research methodology and specific limitations I encountered over the course of running this research study, including data loss, and the potential for bias in children's evaluations. Next I propose an experimental research design that could be applied in future work to help explore and validate whether sound in Mind-Full could improve children's experience while practicing self-regulation. I conclude this chapter by summarizing recommendations for working with children as design partners and co-designing sound. I reflect on the guidelines put forward in chapter two, identifying which recommendations worked, and what changes would be helpful for researchers running co-design studies in the future.

5.1. Co-Designing Sound

5.1.1. Children's Participation in Co-Design of Sound

When developing new technologies its important to keep users in mind. Co-design democratizes the design process (Muller & Kuhn, 1993), and gives users a voice in how tools are developed (Kensing & Greenbaum, 2012). Even though children are frequent users of technology, they are rarely given roles in the design process beyond that of being a user, or tester (Druin, 2002). Moreover, there is a power imbalance between the adults building technologies and the children who use them. Involving children in the design process reduces this power imbalance. It empowers children while also providing useful insights and ideas from a research perspective.

While working with children on the sound design for Mind-Full, I was occasionally surprised by the types of sounds children identified as preferable for the game in Sessions 3 and 4, as they were not ones that I would have chosen from the list of samples. For example, the bird sound that was selected was not (to me) the most relaxing of the options presented. This was an example of how the final product was different than what it would have been if I had designed the sounds myself. Note that I did not come up with sound ideas in advance of the study in order to reduce the risk of biasing the final results.

Taking part in co-design activities had advantages for the children as well. Children learned not only about BCI technology, self-regulation, and sound, they also learned about iterative design processes, and contributed to the development of a real technology. For a generation inundated by complex technology and educational tools, it may be empowering for them to better understand how technology is built.

While there are many ways that children can potentially contribute to the co-design of sound, they each come with trade-offs. One of the most difficult aspects of this research methodology was having children design sounds using words, and descriptions. Early in the design of this research study, I envisioned working with children using technology to create sound samples of voices, instruments and noisemakers. These could then be collaboratively remixed and reviewed by children during the subsequent co-design sessions. Unfortunately, this process was not feasible with such a large group in this classroom setting. I noted that children attempted to create their own noisemakers in the room by using their bodies and objects to create new sounds, for example when children knocked on the table to imitate the sound of stones.

One of the most powerful aspects of co-design cited in the literature is the ability to take one idea and then build off it—taking the idea in new, and unexpected, directions (Guha et al., 2013). However, in our study, children could only do this verbally, resulting in a co-design process that was more in-line with Scaife and Rogers' (1998) informant-based design. It is possible that enabling hands-on sound creation using digital tools may have provided a more collaborative way to come up with sounds, relying less on researcher interpretations of children's ideas. However, as suggested by Guha (2013) there is no one-size-fits all method for co-design. Researchers must figure out which activities suit the context they are working in.

Based on this study alone, it's impossible to know how effective the sounds are in the final prototype. It's unclear whether they have ecological validity, that is, would children still like the sounds in the app if they were presented to them outside the context of this research? It's possible that the sounds, or the feedback mechanisms (e.g., adding more bird sounds when a user becomes more relaxed) do not actually work well in practice. This is one of the risks of co-design. As designers, we can not take children's ideas and discard or change them as we see fit, as this runs counter to the principals of

co-design. Ideally, if a prototype proved to be ineffective, we would return to the children to share these findings and get their input on any proposed changes.

5.1.2. Generalizability

In this research study, I found that children can participate in the co-design of sound of a neurofeedback game. The specific sound ideas would likely be different depending on the group. However, based on my findings I believe that children of this age would be able to contribute to the co-design of sounds for games and mental health apps more generally. The results of this study may benefit a wide range of researchers and designers working in the development of sound for interactive experiences for children.

5.1.3. The Important Role of Adult Facilitators

During this project I observed the important role adult facilitators play when working with children in the design of new technology. They helped encourage the children to come up with sound ideas, and clarify and elaborate on ideas. Previous researchers emphasize the importance of adult research partners establishing relationships with children (Druin, 2002; Scaife & Rogers, 1998); however, during such a short timeframe for the sessions, it was challenging for researchers to get to know the children well. For me personally this was particularly difficult because I was often setting up and running the activities, not working directly with the children. Having teachers help lead the table group activities was tremendously beneficial as they have expertise in keeping children on-task, and could often be heard encouraging children to participate, giving positive feedback, and occasionally relating the concepts back to unique children's lives and personal interests.

There is an inherent tension here. This work wouldn't have been possible without teachers helping guide students and prompting them with questions, however, in doing so, they maintain their position of leadership and authority within the class. It is possible some children were less willing to participate in activities because of their existing relationship with their teacher or the other school staff. Ideally, researchers would have more time to get to know the children. Perhaps having opportunities outside of the design task to work with children and build a relationship. Without this, some children,

particularly those who are shy, may not feel comfortable contributing during the co-design activities when paired with visiting researchers.

In terms of data collection, following this research study, I have a deeper appreciation for why researchers like Druin (1999) Guha (2013) and Read et al. (2002), recommend having extra adults on hand to work with children at each table—one to facilitate, and one to take notes. The data collected using audio recorders was not ideal, it is noisy, hard to understand, and time consuming to review. When notes are taken by researchers during a session, it is possible to gather ideas together immediately. This saves time, improves validity because of its collaborative nature, and reduces the risk that data is lost due to poor quality recordings or a recorder is stopped.

5.1.4. Guiding Children on Abstract Tasks

The biggest challenge children had while taking part in this co-design study was understanding the constraints on abstract tasks. Although I attempted to provide structure to help guide children's designs, as per Guha (2004). The presentation of the prompts for the co-design activities were possibly a bit complex for children of this age. I believe they could have been structured differently for children to have very specific deliverables. Although the children were able to complete the task, I believe the quality of data could have been improved by asking specific questions, rather than open-ended, multipart questions. For example, rather than just asking them to come up with sounds, asking them to come up with "three specific sounds to go with the pinwheel game". This would ensure that the children completed the task, and would also make the data analysis easier for researchers.

5.1.5. Planning for Technology to Break

I had not anticipated the technical challenges of operating multiple headsets at once. While all the equipment was tested and functioning on its own, the headsets did not work when used at the same time due to Bluetooth interference. This knowledge is useful for anyone hoping to run a neurofeedback study using NeuroSky headsets with multiple participants. These technical challenges led to additional stress for some children, which may have been exacerbated by the attention the children received from their tablemates while playing, and by having strangers doing the troubleshooting (i.e.,

researchers adjusting the headset, ear clip etc.). Fortunately, I had a video to show children on day one which demonstrated the game's functionality. This way they could see how the game worked, even if they did not get to use it themselves. Further, it was helpful that I demonstrated the games to the teacher and school staff because they were able to fill in children's understanding of how they worked. This applies broadly to other research as well; it is beneficial to demonstrate concepts in multiple ways to ensure that children understand the design task.

5.1.6. The Benefit of Seeing Children Interact with Technology

As a designer, it was interesting to see a group of children using the app first-hand. I was able to see it through fresh eyes and find evidence of some of my research assumptions. For example, when a child shushed his classmates as he played Mind-Full in Session 1, I believe he was struggling to focus on the game as the others crowded around him and talked. This may be similar to using the app in a real-world context of a busy classroom. This suggests sound to improve children's immersion could be helpful. The act of having children play the game with headphones alone could help to block out distractions.

I also found it interesting that several children questioned the imagery in the Mind-Full Sky game, which was developed in collaboration with an Indigenous community. The game featured a salmon roasting on a stick, and children commented they did not find it calming. This was useful validation that it is important to consider the cultural values and background of target users when developing games for mental health, as discussed in earlier work (Antle, Chesick, & McLaren, 2018). This recommendation also applies to developing sounds for these games, as per van Geelen (2017).

5.1.7. Strengths of This Approach

Following the completion of this study, I identify that there were a number of specific strengths with this methodological design, in particular, the amount of data gathered, and children's active participation.

Amount of Data Gathered

In this research study, I gathered a considerable amount of data from children, including video, audio recordings, written notes, and research observations. The diverse data allowed for triangulation. Analysis of the transcriptions based on the audio recordings and enabled me to better understand children's ideas related to sounds. The corpus of transcription data was also large enough to be able to run basic text analysis. Having multiple sources also helped with triangulating findings and to contextualize the audio recordings. For example, video recordings enabled me to view what was going on at each table while reviewing the audio transcriptions.

Children's Active Participation

In this co-design study children worked in small teams at tables. Because the groups were paired with teachers, who asked probing questions and encourage children, everyone in the class participated actively in the design of sounds in this research study. All the children took part in the evaluation and shared their ideas on the sounds. The children saw how the technology was built iteratively and came up with ideas that I would not have otherwise considered.

5.1.8. Limitations of this approach

Although I was aware of a number of potential challenges with this methodological design, over the course of running this research study I confronted other limitations that could impact the validity of this work. These include, data loss, challenges with interpreting children's ideas, and final evaluation bias.

Data Loss

The loss of recorded data was a significant challenge. This was not only due to one table's recording device being turned off in Session 2, but also because some children's ideas were not captured by the recording devices. As previously mentioned, this was often due to noise in the classroom or children speaking quietly. Consequently, some children's ideas may not have been included in the research data. Fortunately, because of the written system for rating sounds used in Session 3, and Session 4, the children's evaluations were all taken into consideration when selecting the final sounds.

Evaluation Bias

There is a trade-off when involving children in the design process. You can gather ideas from them, but in doing so, they can no longer provide an objective evaluation of the design. In the final session, I asked the class, and then two specific children, for their feedback on the enhanced version of Mind-Full. The children who responded all reported liking the new version of the application more than the original. However, it is impossible to say whether children responded affirmatively because they genuinely liked it, or if they felt a need to please the research team working with them.

5.2. Future Work

Although I now have a version of Mind-Full that includes sound, it remains unknown whether this improves children's experience while using the game in a school context. Next steps for this work would be to first perform user testing to ensure our prototype has ecological validity. If the prototype proved to be effective, we could then validate our assumptions about including sound to a neurofeedback systems using experimental analysis. Possible research questions could include:

RQ 1: Does the addition of multimodal feedback (audio/visual) improve children's ability to control a neurofeedback game for self-regulation?

RQ 2: Does the addition of sound in a neurofeedback game improve children's feelings of immersion while practicing self regulation?

While there many ways we could approach this research problem, I propose comparing children's performance while using Mind-Full under three conditions: playing with visual feedback only; playing with audio feedback only; and (3) playing with multimodal (combined audio/visual) feedback.

Using a within-subjects design, children within the target age range for Mind-Full (5-11) would play the game for ten minutes during six sessions. Children would play each game in counterbalanced order for two concurrent sessions. Participant's game data could be logged and compared under the different conditions.

There could be three measures of the dependent variable. First, algorithmically calculated scores from the headset showing how quickly participants can enter into a

calm/attentive state. Second, algorithmically calculated scores from the headset showing how long participants can maintain a calm/attentive state. Third, self-report survey scores from participants regarding their feelings of control and immersion. By comparing quantitative reports of game performance log data, and qualitative assessments of feelings of immersion, I could determine whether combined multimodal feedback should be included as a default design for future research studies with Mind-Full.

5.3. Recommendations for Co-Design with Children

5.3.1. Co-Design Guidelines

Before starting this research study, I compiled a series of guidelines based on the co-design literature. These guidelines informed my study's research protocol. Over the course of the study, however, it became clear to me that some ideas were better in practice than others. In the following section, I reflect on my proposed guidelines and report any changes I would implement for future studies.

Guideline 1–Choose an Appropriate Age of Children

Children of this age (8-9 years old), were able to participate in the co-design sessions. I believe that co-designing with this cohort worked well. It was helpful they were slightly older than the age of children for whom sound design was originally proposed for, as per the recommendations of Scaife & Rogers (1998). They understood the tastes of individuals of this age but were able to provide better insight than a younger cohort likely could.

Guideline 2–Choose an Appropriate Environment

As suggested in the literature, this co-design study could be run successfully in a school environment (Guha et al., 2013; Read et al., 2002). Some benefits included: the environment was familiar for children, I had access to classroom areas and equipment, and the children were already there. However, I would recommend making two updates to the guidelines I proposed. First, the environment should be consistent from week to week. Switching classroom locations multiple times was challenging in terms of planning, and data collection. It was difficult to know how to arrange the classroom in advance, or where to place the recording devices to minimize interference from other

groups. Since the location kept moving, I could not make changes based on what I had learned from the previous session (e.g., which placement of recording devices works best). Second, I suggest using an environment that allows for groups to be physically separated from each other. This would improve the quality of the recordings, and reduce distractions.

Guideline 3–Determine an Appropriate Frequency to Meet

In this research design several hours of data review was required between sessions. While the dates the school had available for this study were in line with my proposed guidelines (i.e., meeting weekly), completing the review of the data between sessions proved difficult. This could be addressed in future studies either by having more time scheduled between sessions, or by changing the method of data collection.

Increasing time between sessions has drawbacks. In my interview with the teacher following the study, the classroom teacher mentioned that having a full week between sessions is possibly too long. She identified that it is difficult for children to remember what they did that long ago, and instead recommended that sessions be held closer together. Therefore, changing the data collection method would be a preferable method to address the challenge of reviewing data. Previous researchers suggest having adult facilitators take notes instead of relying on recorded data (Druin, 1999). By meeting after each co-design session to review each facilitator's notes, data review could be completed in a fraction of the time, findings may be more reliable because children's ideas would not be lost in a noisy recording, and may improve validity since all the researchers could collaboratively review their notes each session. However, this would necessitate having more researchers on-hand for activities.

Guideline 4–Determine Appropriate Group Sizes for Co-Design Session

For these co-design activities, having groups of 3-5 children worked well. However, if possible, I would recommend working with fewer children overall. This would increase the ratio of adult facilitators to children, could improve participation, facilitate data collection, and make it easier for children to recognize their contribution to the co-design process.

Guideline 5–Minimize Power Imbalance Where Possible

When working in a school environment, it is impossible to eliminate the power imbalance entirely (Druin, 2002). Although I did speak to the researchers and school staff about possible strategies to minimize this impact in advance, it's unclear to what extent wearing informal dress, using first names, and giving children the freedom to speak without raising their hands, reduced the power imbalance. One recommendation I have based on this research study would be to have the researchers visit the school for a few additional classes in advance of the codesign sessions and collaborate with children on activities unrelated to the research. This would give the researchers and children a chance to become familiar with each other in preparation for becoming design partners.

Guideline 6–Ensure There is Mutual Benefit

It is important that co-design activities do not just gather ideas from children, children should benefit from the activities as well (Bratteteig et al., 2012). In our study, children had opportunities to learn not just about co-design, but also about brain-computer interfaces, self-regulation and sound. It was helpful to schedule dedicated time in each session for learning, as it gave children the knowledge and vocabulary needed to participate in the day's activities. I would recommend for future co-design studies, that children do not do any co-design activities until they've done a learning task directly related to the topic. As I learned in Session 1, children do not necessarily have the foundational knowledge to complete a task (i.e., children identifying smells instead of sounds), and this helps ensure abstract constraints are clear.

Guideline 7–Define the problem & domain

To design for a technology, participants must first understand how it works (Bratteteig et al., 2012). It was useful to spend Session 1 explaining the Mind-Full system and the research goals to the children. It was particularly helpful to have a video available on the first day to illustrate how the game worked, especially since there were unexpected technical issues with the equipment. If I were to run a similar study, I would recommend not having children use a technology in a group setting to learn how it works. Playing a relaxation-based game such as Mind-Full in front of peers may cause children to experience stress. Instead, if possible, I would emphasize doing hands-on demos in a low-stakes one-on-one setting.

Guideline 8–Structure Activities in Advance

It was beneficial to structure the goals and activities for this co-design research in advance. It helped me keep children on track in terms of deliverables required from each session. If I were working on a co-design study with this age cohort again, I would examine existing worksheets and activities used in their classroom, to help encourage ideation while also providing appropriate constraints. This could help keep children on task, giving them concrete deliverables to respond to research questions, and make their feedback easier to interpret. Further, I would speak to the classroom teacher in advance to find out what length of session they recommend, as a full hour proved too long for this cohort.

Guideline 9–Ensure Children See Their Work Represented

My guidelines recommended that researchers should help children see the way their work contributed to the final design, as per Guha (2004). It was helpful to check in with the children regularly to share how their work contributed to each stage of the design process. I think it would be helpful to also emphasize to how the evaluation process would take place in advance. Explaining how each stage of the design process would contribute to the final outcomes so the process is open and transparent.

5.3.2. Co-Designing Sound

Co-design is an exciting way to create new technology in partnership with users. Participant ideas can take designs in new and unexpected directions (Guha et al., 2013). However, co-designing sounds comes with unique challenges. Many examples of co-design with children in the literature involve having children devise low-tech prototypes by creating drawings and sculptures, and then bringing them together, often combining ideas by physically cutting them out and gluing them (Druin, 2002; Guha et al., 2004). It is technically challenging to do this with something as intangible as sounds. It is hard to approximate sounds with one's body and voice, and without recording devices to make sound samples that children could listen to, children can not easily reflect on the sound ideas they created. Based on my findings in this co-design study, I believe one could approximate this experience with sound by providing tools for children to easily record and remix sound samples in the co-design sessions. By allowing children to create samples themselves, and manipulating them with audio

technology, children would be able to replay and reflect on them on the spot. Participants would therefore have greater control over the final prototype design.

Chapter 6. Conclusion

Many children experience challenges with mental health, often relating to anxiety and attentional challenges. These could lead to challenges in the classroom, impacting not only children's educational achievements, but also negatively affecting self-esteem. Research suggests that portable neurofeedback treatments may be helpful for teaching children self-regulation, which in turn may help manage symptoms of these mental health issues.

One example of a portable neurofeedback system is Mind-Full, which uses a NeuroSky EEG headset paired with a game that runs on a tablet device (Antle, Chesick, & McLaren, 2018). This system has demonstrated encouraging results in both Asian, and North American research contexts. Exit reports from a recent research study in North America suggest that Mind-Full could benefit from the addition of game sound (Antle et al., 2019). Like many other neurofeedback games, Mind-Full relies on visual feedback. As users gain focus or relax, the game visuals respond on-screen in real time. The emphasis on visual feedback can create difficulties in the field—schools are often noisy and filled with distractions, and some children are uncomfortable sitting in silence with adults. Further, some children prefer to close their eyes in order to practice self-regulation. Incorporating sound into a neurofeedback game such as Mind-Full could improve usability, and potentially outcomes, by providing multimodal feedback and improving children's sense of immersion. However, there is a basic problem: adult researchers cannot assume to know what sounds might appeal to young users. In this thesis, I look to children to guide the development and evaluation of sounds for Mind-Full neurofeedback games.

Co-design is a technique to help give users of a technology a voice in its design. There are many examples of using co-design with children in the literature. Prior to this work, however, there were few examples of the ways that children could contribute to the co-design of sounds for tablet games. In this research study, I attempt to address this gap in the literature, while also contributing to the development of the Mind-Full system. I ran a co-design study over five sessions with 16 children as design partners. This research project took place at a school in Vancouver, and was intended to respond to the following research questions—*In what ways can children contribute to the co-*

design of sounds for a neurofeedback system? and what sounds do children suggest for the Mind-Full Wind neurofeedback system?

The research methodology was developed based on nine guidelines compiled from a review of the literature of co-design with children. Data was gathered in the form of audio recordings, video recordings, children's written notes, researcher session debriefs, researcher observations, and an interview with the classroom teacher. Based on my analysis I found evidence to suggest that children can contribute in the following ways to the co-design of sound for a neurofeedback system: *ideation*—coming up with new sound ideas for Mind-Full wind, *clarification and elaboration*—providing additional information about their ideas, and *evaluation*—listening to sound samples, sharing feedback, and identifying their preferred options. In the audio recordings, I found that children often struggled to stay on task and may have had difficulty understanding abstract constraints. Having teachers available to help facilitate and encourage children's participation was very helpful.

Over the course of the five sessions, children devised and evaluated the following sound ideas for Mind-Full Wind: for the pinwheel game, a breezy wind sound that gets louder as the user becomes more relaxed, and quieter when they are no longer relaxed; for the paraglider game, a chirping bird sound that gets busier (with more bird sounds added), as the user becomes more relaxed, and less busy (bird sounds removed), when the user stops relaxing; for the stone game, a sound of clunking rocks, which can be heard when the rocks fall in hit the ground in the game animation. With the addition of audio feedback it is potentially possible for children to play without visual cues, but this was not tested. The results of this study were influenced greatly by the group of children I worked with and their understanding of the design task. It is likely that if as a researcher I designed sounds for the game they would have been different somehow. However since this was not done in advance, its impossible to say in what way.

In this thesis, I provide some general observations related to the research methodology used in each session, that I hope can be helpful for future co-design and neurofeedback researchers who may wish to adapt and build on my design, as well as some simple text analysis which suggests that teachers tend to use positively coded

language, and that children's participation increased when doing evaluation of existing sounds.

In the discussion section, I propose that children can successfully participate in the co-design of sound for a neurofeedback system. Based on my findings I believe that these findings would be generalizable to applications beyond neurofeedback systems and could benefit games and mental health apps more generally. Researchers hoping to do this type of work should be aware of the important role adult facilitators play, and how to design activities in a way that facilitates children's participation without being too complex. They should also consider that technology demos may break and they should not rely on them exclusively to show children how a system works.

Some of the strengths of this approach include the amount of data I was able to gather from children, which meant that I could triangulate on findings, and reduce concerns about data loss in the audio recordings. Also, my approach allowed for all children to take part in the activities, and have their voices heard for the final design. Some limitations include the loss of data from the audio recordings and the bias children may have when evaluating a system that they worked on alongside the researchers.

As I do not know if this new system featuring sound improves children's experience while using the game, I propose an experimental research design that could be used in future research to validate my assumptions. I conclude with further recommendations for co-design with children. I revisit the co-design guidelines, proposing recommendations I would make to anyone wishing to run a similar study in the future. For example, I advise being consistent in the physical location of the co-design sessions; having researchers join the class in advance of the study to get to know children; and only doing hands-on demos in low-stakes, one-on-one settings. I also provide recommendations on co-designing sound. Specifically, I propose giving children more control over the final prototype by using technology to record and remix samples on the spot. This work offers the following contributions, first, a set of practical guidelines for co-design with children; an enhanced version of Mind-Full Wind that includes children's sound ideas (wind, bird, and stone sounds) to be used in experimental analysis; a summary of the ways in which children can contribute to the co-design of sounds. Finally, insight into the tension between teacher's roles as design partners and facilitators.

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Appendix A. Study Protocol

Session 1	Title: What is Mind-Full?
<p>Goals In Session 1, I introduce the children to Mind-Full (a mobile neurofeedback game to help children learn to self-regulate) and the design task.</p>	
<p>Children will...</p> <ul style="list-style-type: none"> • learn how brain activity relates to feelings of stress, anxiety, and attention • be introduced to brain-computer interfaces that detect and display brain activity on a tablet device • experience controlling their brain activity using the Mind-Full neurofeedback system • see the link between brain activity (cause) and animations on the screen (effect) • reflect on how individuals around the world experience feelings of stress and anxiety • view ways in which research in Canada can affect children living in other countries • come up with initial sound ideas for the app 	
<p>Proposed Schedule–1 hour</p> <p>5 Mins–Complete assent for children to participate in the study</p> <p>5 Mins–Intro to Mind-Full</p> <ul style="list-style-type: none"> • Explain why we built for children in Nepal • Describe how it has been used in Canada • Ask for children’s help to make it better <p>20 Mins–How does it work?</p> <ul style="list-style-type: none"> • User’s brain produces electrical signals, Mind-Full can interpret this activity • Talk about the different games (relaxation/attention) <p>25 Mins–Demo for Children</p> <ul style="list-style-type: none"> • Each child has a turn playing the game • Multiple researchers on-hand to help manage multiple devices at once • Children who are not playing will come up with ideas for sounds for Mind-Full games <p>5 Mins–Thank children for their time and introduce what we will do next session</p>	

Session 2	Title: Sound & Games
<p>Goals In Session 2, I introduce how sound is used in games to convey information, and we come up with ideas about the kinds of sound and feedback that could encourage other children playing Mind-Full.</p>	
<p>Children will...</p> <ul style="list-style-type: none"> • learn about information that can be conveyed using sound, and how sounds can make people feel • consider the effect of using sound feedback in technology • further develop their ideas for game sounds • come up with new sound ideas for the app 	
<p>Proposed Schedule–1 hour</p> <p>5 Mins–Brief review of the previous week’s session 10 Mins–Introduction to sound</p> <ul style="list-style-type: none"> • How sound is used in multimedia and games • Music vs sound effect vs dialogue • How sound can convey feelings <p>5 Mins–Review previous week’s ideas related to Mind-Full Wind 5 Mins–Activity to introduce the way that sound can be used as feedback 30 Mins–Co-design sessions in small groups</p> <ul style="list-style-type: none"> • What sort of sounds could go with the (pinwheel/paraglider/stone) game, and why? <p>5 Mins–Thank children for their time and introduce what we will do next session</p>	

Session 3	Title: Sound Evaluation
<p>Goals In Session 3, children evaluated sound treatments gathered for the pinwheel and paraglider games based on their ideas from Session 2.</p>	
<p>Children will...</p> <ul style="list-style-type: none"> • develop their ability to evaluate new technologies • provide feedback on sounds gathered based on their previous suggestions • better understand how app ideas get created iteratively 	
<p>Proposed Schedule–1 hour</p> <p>10 Mins–Brief review of the previous week’s session</p> <ul style="list-style-type: none"> • reminder of self-regulation and breathing exercises • overview of different types of sounds and feedback <p>5 Mins–Learning activity to reinforce sound ideas</p> <ul style="list-style-type: none"> • Imitate sound ideas as a class <p>30 Mins–Co-design sessions in small groups</p> <ul style="list-style-type: none"> • What do they think of the sounds collected for the pinwheel/paraglider games? • Do they have any new ideas? • Which sounds do they think would go best? <p>5 Mins–Thank children for their time and introduce what we will do next session</p>	

Session 4	Title: Sound Evaluation II
<p>Goals In Session 4, children view a prototype app with the previous week’s sounds included. They continue evaluating sound treatments selected based on their ideas from Session 2 and identify ways to assess the enhanced system.</p>	
<p>Children will...</p> <ul style="list-style-type: none"> • develop their ability to evaluate new technologies • provide feedback on sounds gathered based on their previous suggestions • better understand how app ideas get created iteratively • see their work incorporated into a real system. • identify ways to evaluate the system 	
<p>Proposed Schedule–45 minutes</p> <p>5 Mins–Brief review the previous week’s session</p> <p>5 Mins–Demonstrate how we incorporated sounds into the Mind-Full Application</p> <ul style="list-style-type: none"> • Identify how children’s input contributed to the design <p>25 Mins–Co-design sessions in small groups</p> <ul style="list-style-type: none"> • What do they think of the sounds collected for the stone game? • Do they have any new ideas? • Which sound do they think would go best? <p>5 Mins–Brainstorm as a group how to evaluate the system with other children</p> <p>5 Mins–Thank children for their time and introduce what we will do next session</p>	

Session 5	Title: Evaluation
<p>Goals In Session 5, children see the final prototype and provide feedback on the co-design process</p>	
<p>Children will...</p> <ul style="list-style-type: none"> • share their ideas on the co-design activities • evaluate the enhanced application 	
<p>Proposed Schedule—45 minutes</p> <p>5 Mins—Brief review the previous week’s session</p> <p>10 Mins—Demonstrate how we incorporated sounds into the Mind-Full Application</p> <ul style="list-style-type: none"> • Identify how children’s input contributed to the final design <p>5 Mins—Discussion with children about the co-design experience</p> <p>20 Mins—Two children evaluate the game. The rest of class draws their own game</p> <p>5 Mins—Thank children for their time</p>	

Appendix B. Children's Evaluation Interview Questions

1. What did you think about the sound?
2. What did you like about it?
3. Did you think that the sounds made you more calm, or made you more attentive?
4. What did you like better—playing in silence, or with sound?
5. You saw what it would be like with both the sounds and music. Do you think you would like both, or just them separate?

Appendix C. Teacher Debrief Interview Questions

1. Do you have any thoughts on how the students responded to the sessions that we did?
2. Is there anything you felt went well with the session?
3. Is there anything you felt that we could improve on, or any specific things that maybe didn't go so well?
4. Do you think the kids behave differently in the context of like doing our activities versus what they are normally like in the classroom?
5. Were there any moments in particular you remember, or did any of the kids have any interesting observations?
6. Do you have any final thoughts, or anything you would like to share?

Appendix D. Related Publications

The following is a list of publications related to the Mind-Full project I am a co-author on.

1. McLaren, E.-S., & Antle, A. N. (2017). Exploring and Evaluating Sound for Helping Children Self-Regulate with a Brain-Computer Application. *Proceedings of the 2017 Conference on Interaction Design and Children*. doi: 10.1145/3078072.3084299
2. Antle, A. N., McLaren, E. S., Fiedler, H., & Johnson, N. (2019). Design for mental health: How socio-technological processes mediate outcome measures in a field study of a wearable anxiety app. *Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction*, 87–96. <https://doi.org/10.1145/3294109.3295650>
3. Antle, A. N., McLaren, E.-S., Fiedler, H., & Johnson, N. (2019b). Evaluating the impact of a mobile neurofeedback app for young children at school and home. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, 1–13. <https://doi.org/10.1145/3290605.3300266>
4. Antle, A. N., Chesick, L., & McLaren, E.-S. (2018). Opening up the design space of neurofeedback brain-computer interfaces for children. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 24(6), 1–33. <https://doi.org/10.1145/3131607>
5. Antle, A. N., Chesick, L., & McLaren, E. S. (2017). The effects of neurofeedback games on young children with anxiety and attention challenges. *Society for Neuroscience: Neuroscience Conference*. Washington, D.C. Nov 11-14, 2017. Abstract and poster presentation.