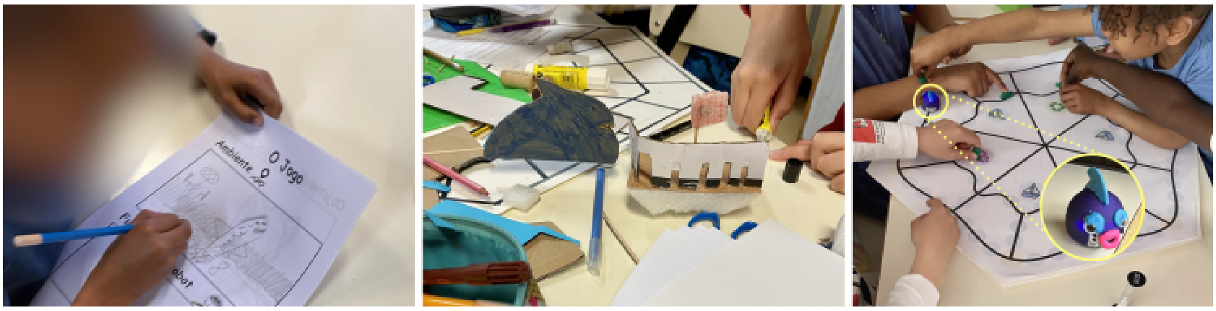

Inclusion through Play: Co-designing Inclusive Robotic Games with Neurodivergent and Neurotypical Children

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Thesis to obtain the Master of Science Degree in

Computer Science and Engineering

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Declaration
I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

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Abstract

Neurodivergent (ND) children are integrated into mainstream schools alongside their neurotypical (NT) peers but often face social exclusion, which may have lifelong effects. Inclusive play scenarios, such as games, are a strong proponent of inclusion. Unfortunately, games designed for the specific needs of neurodiverse groups are scarce. Given the potential of robots in mixed-ability scenarios, we led a co-design process to build an inclusive robotic game for neurodiverse classrooms. We first identified the barriers and facilitators for including ND children in mainstream schools with ND adults and educators of neurodiverse classrooms. Then, we conducted five co-design sessions, engaging four neurodiverse classrooms in designing an inclusive game. We present best practices for co-designing with neurodiverse groups of children. We detail the development process of an inclusive robotic game based on the children's game concepts and its evaluation, showcasing the co-designed game's positive effect on engagement, enjoyment, and group dynamics. Finally, we present guidelines for designing inclusive games, such as prioritizing fun, leveraging various activities, and embracing technological options.

Keywords

Co-design; Classrooms; Children; Robots; Neurodivergent; Inclusion; Games; Neurodiversity.

Resumo

As crianças neurodivergentes (ND) são integradas nas escolas regulares juntamente com os seus pares neurotípicos (NT) mas enfrentam frequentemente exclusão social, que pode ter efeitos para toda a vida. Os cenários de brincadeira inclusiva, tais como jogos, são um forte proponente para a inclusão. Infelizmente, os jogos concebidos para as necessidades específicas dos grupos neurodiversos são escassos. Dado o potencial dos robôs em cenários de capacidades mistas, conduzimos um processo de co-design para construir um jogo robótico inclusivo para salas de aula neurodiversas. Começámos por identificar as barreiras e os facilitadores da inclusão de crianças ND em escolas regulares com adultos ND e educadores de salas de aula neurodiversas. Depois, realizámos cinco sessões de co-design, envolvendo quatro salas de aula neurodiversas na concepção de um jogo inclusivo. Apresentamos as melhores práticas de co-design com grupos de crianças neurodiversas. Detalhamos o processo de desenvolvimento de um jogo robótico inclusivo baseado nos conceitos de jogo formulados pelas crianças e a sua avaliação, demonstrando o efeito positivo do jogo co-designed no envolvimento, diversão e dinâmica de grupo. Por fim, apresentamos directrizes para a concepção de jogos inclusivos, tais como dar prioridade à diversão, alavancar várias actividades e abraçar as opções tecnológicas.

Palavras Chave

Co-design; Salas de aula; Crianças; Robôs; Neurodivergente; Inclusão; Jogos; Neurodiversidade.

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Acronyms

ADHD Attention Defficit Hyperactivity Disorder

AR Augmented Reality

ASD Autism Spectrum Disorder

CDBW Co-Design Beyond Words

CD Co-Design

CECD C.E.C.D. Mira Sintra - Centro de Educação para o Cidadão com Deficiência

D4D Diversity for Design

DIX Disability Interaction

DIY do it yourself

FASD Fetal Alchohol Syndrome Disorder

GDD Global Developmental Delay

GUESS-18 Game User Experience Satisfaction Scale

HCI Human-Computer Interaction

HRI Human-Robot Interaction

ID Intellectual Disability

IST Instituto Superior Técnico

LD Learning Difficulties

ND neurodivergent

NT neurotypical

ODD Oppositional Defiant Disorder

PD Participatory Design

SUS System Usability Scale

UCD User-Centred Design

UX User Experience

1

Introduction

Contents

Play is an essential aspect of childhood, and it is intrinsically linked with development [2, 3]. Children acquire, consolidate and display skills through play activities [4–7]. Childhood socialisation mainly happens through play, allowing children to observe and learn from their parents' and peers' social behaviours [8]. While playing, children develop friendships, learn to negotiate and cooperate, develop communication skills, and train their dexterity [9, 10]. Beyond the developmental benefits, play is a source of joy and fun, allowing children space for self-expression and exploration [8, 9]. UNICEF recognises play as a children's right [11]. Games are widely used to unlock the benefits of play, offering pleasurable engagement and positive outcomes for players' well-being [12, 13]. Moreover, they have the potential to promote inclusive experiences and equally engaging experiences for players with and without disabilities [14].

However, neurodivergent (ND) players still face reduced opportunities for inclusive play experiences and access to their associated benefits. Throughout this document, we use the concept of *neurodiversity* to address the multitude of neurological differences in human brains, which operate within the identity model of disability [15, 16]. We acknowledge neurological differences as an expression of the variety of human brains where most brains are neurotypical (NT), and 15% to 20% of the global population diverges from these norms and thus, referred to as ND [17]. Conditions commonly categorised as ND include: "ADHD, autism (ASD), dyslexia, [...] intellectual disabilities and schizophrenia" [18]. ND individuals are moreso hindered by society's expectations of neurotypical behaviour than by their conditions [18, 19]. These individuals present heightened senses of creativity, among other skills, and often outperform their NT peers [17–19].

1.1 Problem Statement

ND children, similar to their NT peers, require inclusive play experiences, which may be facilitated through games [12, 13], for successful development [2–10]. In a recent critical review of games and playful systems developed by the HCI research community specifically targeting ND players [20], Spiel and Gerling show that games are largely designed for medical and training purposes (i.e., serious games). The main goal of these games is to dress up boring and repetitive activities, which tend to prioritise training over play and are driven by factors extrinsic to neurodivergent interests. Moreover, games are designed with a top-down approach and intended to be used by ND players alone, reducing opportunities for social interaction and inclusive experiences.

ND children integrate classrooms alongside their NT peers on a daily basis. However, due to differences in interests and communication styles [21], ND and NT children often struggle to find play activities that are engaging for both parties [22]. With ND children being the minority in most classrooms, this deficit can lead to social isolation. It is imperative to find ways to promote and support inclusive play within mainstream classrooms to benefit all children. Previous research [14] shows the potential of using co-design methodologies and off-the-shelf robots to engage mixed-ability groups in creating games that promote inclusive play experiences. We aim to employ these techniques in the under-explored setting of neurodiverse classrooms, promoting the inclusion of ND children.

1.2 Approach

In this dissertation, we built an inclusive robotic game aimed at neurodiverse groups of children, which promoted inclusion and enjoyment. We achieved this by taking on a multiple-methods approach with various stakeholders. Firstly, we aimed to identify existing barriers and facilitators to inclusion in mainstream classrooms. Therefore, we started with a focus group discussion with 13 educators to uncover the challenges and opportunities in working with neurodiverse classrooms. Simultaneously, we conducted six individual interviews with ND adults to empathise with first-hand accounts of school and play experiences.

Following these formative studies, we ran a five-week-long co-design process with four neurodiverse classrooms (totalling 20 co-design sessions) to create an inclusive game using Ozobots [1] (Figure 5.1). We started this process by building rapport with the children and educators. Through playful activities, we introduced them to the Ozobot and its functionalities. Leveraging Expanded Proxy Design [23], children formulated initial game concepts consisting mainly of narrative elements. We analysed these concepts, establishing a basic game structure, which children built upon in the following sessions, defining mechanics and artefacts, and play-testing their creations. From this co-design process, we derived a set of best practices for co-designing with neurodiverse groups of children in classroom settings. Furthermore, we reflect on the bilateral impact between the co-design process and the classroom setting.

Analysing the prototypes and concepts generated by the children during the co-design sessions, we distilled trends and innovative ideas. Building upon these with more structured game mechanics, we developed a low-fidelity prototype. Through an iterative design process, which included a workshop with game design students, informal testing sessions and a pilot test with ND adults, we incrementally play-tested and improved upon this prototype, leading to the design of a high-fidelity version.

To validate our game, we conducted a final play-test in neurodiverse classrooms, including those participating in the co-design process and an additional control class. From this evaluation, we propose a set of recommendations for designing games aimed at neurodiverse groups.

We aim to answer three main research questions:

1. What are the barriers and facilitators to inclusive play in mainstream schools?

2. How to engage groups of neurodiverse children in co-designing inclusive robotic games?

3. How does the resulting game support inclusive play?

To achieve these goals, we take on the viewpoint of the social model of disability [19], understanding the traits of ND individuals as inherent and attempting to shift our preconceptions and adapt our methodologies to include them, allowing them to express their own voices, rather than force them to adapt to neurotypical standards. The objective of our process is not to alter the behaviour of these children but to provide them and their peers with support for engaging and inclusive play experiences.

1.3 Contributions

Building upon previous research, we add to the existing literature on barriers and facilitators to inclusion in mainstream classrooms. Considering the novelty of mixed-ability co-design with ND and NT children, we explore co-design methodologies, informing future research on best practices. Finally, we deliver a set of design guidelines for developing inclusive games for ND and NT children, together with an inclusive robot-based game leveraging off-the-shelf robotic toys and its evaluation in a classroom context.

1.4 Paper Submissions

Regarding the work encompassed in this dissertation, we have submitted a full paper under review for the International ACM SIGACCESS Conference on Computers and Accessibility 2023 (CORE A) under the title: **"We all win": Co-Designing Inclusive Robotic Games with Neurodiverse Classrooms** [Submitted]

Furthermore, regarding research conducted concurrently with this project, we have published a poster in the International ACM SIGACCESS Conference on Computers and Accessibility 2022 (CORE A) under the title: **Co-designing a Bespoken Wearable Display for People with Dissociative Identity Disorder** [Accepted], and a full paper in the ACM/IEEE International Conference on Human-Robot Interaction 2023 under the title: **"The Robot Made Us Hear Each Other": Fostering Inclusive Conversations among Mixed-Visual Ability Children** [Accepted]

1.5 Document Structure

This document is structured as follows. Chapter 2 details concepts relating to inclusive play and neurodivergence, grounding the following research. In chapter 3, we present a literature review of previous works relating to Game Design, with a focus on games designed for mixed-ability groups, ND players, and neurodiverse groups, Human-Robot Interaction (HRI), highlighting studies involving robots and ND individuals, and Participatory Design (PD), specifically participatory methods aimed at including child, disabled or ND individuals. Chapter 4 outlines the timeline of the project and reports on the formative studies conducted to understand the challenges and opportunities for promoting inclusion in a mainstream classroom, detailing the procedure and participants of both the educator focus group and the interviews with ND adults. This chapter culminates in a list of barriers and facilitators to inclusion in mainstream classrooms, combining the findings of both studies. In chapter 5, we present the methodology for the Co-Design (CD) sessions, alongside observational insights relating to the efficacy of CD methodologies and the children's behaviour. We discuss these findings, reflecting on the bilateral impact of the CD process in the classroom and vice-versa and proposing a series of best practices for co-designing with neurodiverse groups. Chapter 6 details the final game design and its iterative design process, reporting on the analysis of the game concepts generated by the children during the CD sessions and their refinement into a fully functional prototype. The evaluation of these prototypes in neurodiverse classrooms is presented in chapter 7. This chapter closes with a discussion of the evaluation's results, defining recommendations for designing games for neurodiverse groups. The document ends with a conclusion, summarising this dissertation's contributions and proposing future work, in chapter 8.

2

Background

Contents

This chapter describes relevant concepts and research findings outside the Computer Science and Engineering domain that inform this project.

2.1 Inclusive Play

As this work aims to generate inclusive play experiences, it is essential first to understand what inclusive play is and what previous research has found to be its barriers and facilitators.

Inclusive Play is characterised by its openness to all participants, regardless of cultural background or ability; it is educational and fosters positive relationships among children with significant differences. By promoting inclusive play, we encourage children to empathise with their peers, developing into more emotionally and socially intelligent adults. [22, 24]

Sobel et al. [20] conducted a literature review, an ethnographic observation of an inclusive classroom and a survey of parents and educators to understand the current challenges and opportunities within the inclusive education space. The central objective of this study was to determine how technology might aid in creating inclusion through play, specifically in the case of classrooms with ND and NT children. The research team found five categories of inclusive play facilitators: support, transparency, flexibility, children's interests and technology. The authors list four challenges in promoting inclusive play: effort, play styles, lack of experience and concerns with time spent on screen-based activities.

Bulgarelli [25] reports on a study on the perspectives of Italian early childhood educators on promoting inclusive play. The project aimed to characterise the strategies used by these professionals to facilitate said inclusion and the difficulties or barriers that stood in the way. The surveyed practitioners identified ASD as the most common disability among the children they work with, followed by children with intellectual disabilities and visual impairments. Regarding toys, practitioners pointed out the needs of children with ASD and the importance of avoiding stereotypes and triggering stimuli when designing play objects for this group. Overall, educators saw toys as a helpful tool to foster inclusion within the classroom. Adults can act as observers, activators or partners when facilitating inclusive play. The activator was the most common role, outlining the play activity and motivating children to participate. Most of the questions that made up the study were multiple-choice, limiting the answers' depth.

Morris et al. [21] detail findings from interviews with six inclusive education professionals with experience in promoting inclusive play in neurodiverse groups. Aiming to find current barriers to social play and design insights, researchers leverage the "double empathy problem" as a lens to analyse the participant's responses. When asked about play in neurodiverse groups, professionals tended to focus their answers on the accessibility barriers of ND children rather than those of their NT peers. The authors reframe their findings from the perspectives of both sets of children, providing a holistic view of the problem space. The main barriers included differences in communication styles, sensory needs and rule-following in play. NT children tend to follow their accustomed communication methods, misinterpreting communication cues from their ND classmates. ND children attempt to integrate into neurotypical society by identifying social rules. However, the ambiguity of these norms makes this process challenging, and their NT peers do not respond well to understandings different from their own. The strong adherence to rules by NT children in play scenarios also contrasts with their ND friends' desire to play on their terms. These findings are limited due to the small number of second-hand accounts but may be useful in informing design research with neurodiverse groups.

2.2 Neurodivergence

To better understand the needs and strengths of our ND co-designers, we must first form a theoretical understanding of what neurodivergence is. Neurodivergence or neurodiversity is an umbrella term for a series of diagnoses related to cognitive differences and movement to reframe such conditions as differences rather than deficits.

As a movement, neurodivergence bases itself on three pillars. The first is the upsides of these conditions, positive traits more commonly found in ND individuals. By focusing on such talents rather than the limitations of differences in cognition, neurodivergence finds value and identity in difference. The second is the social model of disability. This model considers disability as something brought on by society and not inherent to the individual. The traits we may consider disabling today would be irrelevant or extremely useful in different societal contexts. Therefore disability is brought on by society's expectations of "normalcy" and its discrimination of anything othering. The final factor is the Spectrum of Disorder. This concept points to the differences within the same diagnosis or even the differing diagnosis for the same condition, prevalent in ND conditions. Neurodivergence must be considered in its full diversity, not by taking diagnoses at face value but by understanding each individual's specific and varying needs [19].

The term neurodivergence was initially associated with Autism Spectrum Disorder (ASD). However, over the years, it has grown to include many other innate conditions characterised by different ways of thinking and experiencing the world [18]. Doyle [17] estimates 15% to 20% of the world population is ND. Below is a list of the most commonly referenced acsND conditions in literature and some of their characteristics:

- ASD - Often referred to as simply autism, ASD manifests in difficulties communicating, socialising and dealing with sensory stimuli [17, 18]. Individuals are often diagnosed with specific disorders within this spectrum, such as Asperger's. However, as we understand the non-linearity of spectrum disorders and the variability of needs, classifications based on functioning labels tend to fall out of favour within the neurodivergence movement [26]. People with ASD are known to excel in memorisation, specific knowledge domains they become passionate about, and attention to detail [17, 18].

- Attention Defficit Hyperactivity Disorder (ADHD) - More commonly known by its acronym, ADHD is associated with difficulties in time management, focus and the fulfilment of sensory needs. The spontaneity and impulsiveness of individuals with ADHD gives them an advantage in creative tasks. Moreover, though they have difficulty finding concentration when a focus stage is achieved, ADHDers are known to remain on-task for extraordinarily long periods. [17, 18]
- Dyslexia - Individuals with dyslexia often struggle with reading and memorisation tasks, confuse similar-sounding phonemes and are prone to spelling mistakes. People with dyslexia have an innate ability for big-picture thinking and visual information processing [17, 18]. Dalton [19] notes the prevalence of this diagnosis in creative fields such as HCI.

Other conditions under this umbrella include Dysgraphia, Fetal Alchohol Syndrome Disorder (FASD), Cerebral Palsy, Dyspraxia and Trisomy 21 (Down Syndrome) [20]. The label NT pertains to individuals who display common cognitive traits and abilities, therefore not ND [17].

2.3 Neurodivergence in HCI

As Human-Computer Interaction (HCI) evolves to see beyond the typical user and toward an Inclusive Design point-of-view, researchers explore the alternative perspectives stemming from designing with and for users with disabilities.

Holloway [27] outlines the opportunities and objectives of the multidisciplinary field within HCI, Disability Interaction (DIX). DIX views disability as more than the limitations it might bring to Interaction Design, focusing on the paradigm-shifting opportunities it brings. By empowering the end-users to create solutions and fulfil their needs with the help of technology, DIX aims to generate innovation, accessibility and inclusion. The proposed field of study leverages the existing internet "maker" movement and encourages people with disabilities to create working solutions to the challenges they know best. The value of DIX designs is in their usefulness, not monetary gain. According to DIX, co-creating solutions with people with disabilities will lead to disruptive concepts and an understanding of the wants and needs of this underrepresented community.

In the specific context of cognitive disabilities, Dalton [19] introduces the growing neurodivergence movement and considers its applications within the context of HCI. Dalton brings up three main aspects from the literature that characterise this movement and how these can benefit future HCI research. The author proposes that focusing on the upsides of neurodivergence will lead to ideas and creations beyond what is possible from a neurotypical framework. Dalton points out the benefits of inclusive design and what we can achieve by not just catering to the NT user. Dalton finalises with a call to action for the inclusion of neurodivergent lenses and ND designers in future HCI research.

Motti [28] presents a literature review of methodology in research projects related to the development of smart technologies for neurodiverse users and a list of recommendations for future UX studies in this domain. The study's objective was to guide the inclusion of neurodiverse users in the PD of technologies geared towards them. The author recommends several design considerations for future research. Instructions should be clear and accessible and offer multimodal feedback. Studies should take place in settings comfortable to their users. Researchers should include demographic data to its full extent and with transparency. Motti recommends multimodal feedback within the technology to keep the users calm, focused and engaged. Designers must also consider the users' comfort when creating devices or environments. Due to the sensory differences within this population, researchers should aim to identify and minimise stress sources within the technology and research activities. Positive feedback is an essential motivator for this population. When considering neurodiverse users, respecting and accounting for their diversity between and within diagnostics is crucial. Therefore, technology should be customisable to users' preferences and needs.

3

Related Work

Contents

This chapter encompasses an overview of previous research relevant to the project. As a background for our game design process, section 3.1 details relevant elements of a game and examples of games formulated for mixed-ability gaming, neurodivergent players and neurodiverse groups. To support our use of robots as game elements, section 3.2 documents previous HRI research related to ND individuals. Finally, to inform the design of the CD workshops, section 3.3 provides examples of participatory methods used with children, children with disabilities and ND individuals.

3.1 Game Design

A game is "a problem-solving activity, approached with a playful attitude" [29]. Furthermore, as the name implies, Game Design consists of the processes and artefacts related to creating a game. It is the art of deciding what makes up a game, the step before implementing the game [29].

Schell [29] lists four central elements that constitute a game: mechanics, story, aesthetics, and technology. Mechanics determine how a game works, its rules and its goal. This element determines everything a player can and cannot do at each point in gameplay. Game mechanics dictate the definition of space within a game and how a player may move within it. How time flows, whether by a continuous clock or by turns. What objects exist within the game, including characters, tokens and scoreboards, what attributes they may possess and in what states these objects can exist. What secrets does the game withhold from its players, and which ones do they keep from each other. What actions, strategic or basic, a player may take; what rules exist, who enforces them, whether they are constant or vary by game mode and how cheatable they are. Moreover, what skills does the game require the player to have or acquire to be successful, be it physical, mental or social. The story pertains to the sequence of in-world events that happen throughout gameplay. These may be linear and pre-scripted or built by the players each time. Game stories often follow traditional narrative arcs like the hero's journey. They are a crucial factor in captivating and maintaining the player's interest. Designers must carefully consider their peaks and ends to deliver enjoyable and memorable play experiences. Aesthetics are the sensory outputs the game gives the player. They include the visuals, sounds, smells, tastes and tactile feedback a game may use to interact with its players. Well-crafted aesthetics optimise player immersion and engagement. Technology encompasses all the physical game artefacts a player interacts with, including tablets, gameboards, robots and playing cards. This element moves the game from concept to reality, giving the player an interface to interact with all the other elements.

Beyond these, Schell names flow and balance as important concepts. Flow or game flow is a specific state of focus and engagement desired during gameplay. When a growing challenge supports the player's growing skills, their emotions find the perfect in-between of anxiety and boredom: the flow channel. Shell recommends defining objective goals, minimising distractions, and providing immediate feedback after each in-game decision to achieve this state. Balances are central to game design. For instance, balancing roles within a game can completely change the gameplay experience. Symmetrical games, like Monopoly, give each player the same role, task and resources. Competitive games are often symmetrical. Asymmetrical games do the opposite, giving players different roles and starting points. Asymmetrical game design is most common in cooperative games.

3.1.1 Mixed-Ability Gaming

As highlighted in section 2.1, ludic activities, such as games, that include players of diverse abilities benefit all players. In this section we address previous work pertaining to the design of such games, excluding those aimed at neurodiverse groups, addressed in section 3.1.3.

In an early contribution to mixed-ability gaming, Brederode et al. [30] describe the design process of a mixed-reality collaborative game leveraging tangibles and AR: *pOwerball*. *pOwerball* aimed to promote inclusive and social play among children with and without disabilities in a classroom setting. Designers involved 31 children with and without physical disabilities in establishing design goals and testing various prototypes. The design process began with an inquiry of the children's educators and contextual interviews with the children, leading to the establishment of design goals, such as equalising gameplay, promoting dialogue, prioritising fun and leaning into current "cool" design trends. The initial validation of the resulting game concept highlighted the balancing effect of conjugating skill and luck-based mechanics and the need for a competition element to promote engagement. The final design of *pOwerball* enabled equal participation of all children and stimulated social interaction, though the children desired more competitive mechanics. The authors emphasise the benefit of involving children in the design process but acknowledge the potential of more participatory approaches, which were unfeasible due to the project's timeline.

In the realm of adaptative sports, Graf et al. [31] report on the development and testing of an AR platform targeted at users with different levels of mobility: *iGYM*. This system consists of a floor projection of a game field and a virtual ball. Sensors detect the players' movements and kick buttons that allow users with limited mobility to interact with the ball. The ball's virtual nature allows the game developers to adapt in-game physics to each player's ability. The study aimed to evaluate different game characteristics and how the adaptions influenced the perception of gameplay. Researchers conceptualised an example, an air hockey-inspired two-player game, to conduct a play-test. The designers established three levels of mobility aids with pre-set in-game adaptions: no mobility aid, power wheelchair and manual wheelchair. Mixed pairs of users aged 7 to 19, with and without different levels of mobility impairments, participated in testing *iGYM*. The players enjoyed *iGYM*'s closeness to traditional sports, the lack of special equipment needed to play and its affordances for competitive mixed-ability play. They saw the game as fun, fair and inclusive. Factors like familiarity with the opponent and personal preferences may have influenced results.

Gerling & Buttrick [32] present Last Tank Rolling, a collaborative two-player motion-based game aimed at mixed-motor-ability pairs. Last Tank Rolling allows a player in a wheelchair and a non-disabled peer to control a virtual tank and soldier through a KINECT. The designers' main goal was to promote inclusion, empathy and engagement among players of different abilities. The interactive prototype described in the article was set to be tested with mixed-ability players in a school setting. However, we did not find reports of this testing's results in this or subsequent articles by the authors.

Regarding serious games, those which hold learning goals as their primary focus, Neto & Galasso [33] and Escudeiro et al. [34] developed prototypes aimed at including players of various disabilities (deaf [33], blind [33, 34], colour-blind [34] and with mobility impairments [34]) in learning about, respectively, Morse code and Chemistry. Developers leverage audio descriptions [33], sign language [33, 34], the use of symbols rather than colours [34], and alternative input devices [34]. Both articles provide expert evaluations of the game's design. Still, the only insights from play-testing with their target demographics pertain to usability, contrasting with their shared goal of social inclusion through play.

Gonçalves et al. [35] explore asymmetric roles in mixed-ability gaming by developing and subsequently testing two prototype cooperative games targeted at mixed visual ability teen and adult users. The study aimed to evaluate the engagement of asymmetric games and the impact of this scenario on the users' sense of competence and autonomy. By attributing different in-game roles to players depending on their ability, asymmetry attempts to bridge the gap between the two player groups. One player would be in charge of an audio-based task while the other would focus on a visual challenge, communicating synchronously to reach their goal. Thirteen mixed-ability player pairs tested the games in a remote user study. The whole testing group showed positive affect towards at least one game. The majority considered the experience fun regardless of their abilities. Information asymmetry between the player roles pushed the players towards active communication, which they considered a highlight of the experience. Participants noted that the asymmetric nature of the game required a sighted person to function. This lack of flexibility limited its inclusivity.

Within the context of an inclusive classroom, Metatla et al. [14] attempt to bridge a social gap by co-designing an inclusive robot-based educational game with and for visually impaired and sighted children. The research team led a focus group with experts on the education of visually impaired children. From this discussion, they gathered a series of relevant challenges to mixed-ability inclusive play within the school context. Following this, the authors conducted four co-design workshops with visually impaired and sighted children within a classroom context. During said workshops, the children participated in the co-creation of an educational game featuring off-the-shelf robots (Ozobots). The authors contribute a list of guidelines for inclusive mixed-ability educational game design, notably the importance of crafting, multi-sensory feedback, narration and curricular learning goals. Additionally, the results of play-testing the game showed promise for co-design as a methodology for creating inclusive games. It raised awareness of the accessibility needs of visually impaired children to their peers and gave the children a sense of ownership over the game. The workshops promoted the development of social skills among the children, as they organically divided work and shared roles to achieve a common goal. The main limitation lies in the play-testing process, as this step was carried out only once with the children who participated in the co-design process.

3.1.2 Games for Neurodivergent Players

From a User-Centred Design (UCD) standpoint, minorities, such as neurodivergence, require designs according to their needs and interests. For a thorough review of games research for neurodivergent players, Spiel & Gerling [20] conducted a literature analysis of 66 HCI papers written between 2005 and 2019. This section describes relevant examples of games explicitly designed for neurodivergent players.

To promote enjoyable physical exercise, in the form of hikes, in users with intellectual disabilities, Torrado et al. [36] detail the development and testing of an Android-based game: *HikePal*. The concept of *HikePal* consisted of a narrative reward system where the user physically followed a path to unlock different story points. The researchers aimed to understand how to design motivating exercise-based games for this population, create an appropriate navigation system for the target users and what aspects are relevant for game and application design within the scope. Informed by two focus groups with experts, the team developed iterative prototypes, arriving at a functional version tested in the user study. This test consisted of two hikes using the prototype, followed by group interviews. The participants include three members of the target demographic, individuals with intellectual disabilities aged 16 to 35, and two caregivers. Users found the app fun, though only two out of the three reported a desire to play again. However, this enjoyment was not related to the narrative aspect. Unexpectedly, the social interaction brought on by the user test was the most motivating feature. The authors deliver design considerations for developing exergames for users with intellectual disabilities. These include a desire for customisation and automation within the application; the added challenges of using an application outdoors; the need for alternative paths, such as back buttons; and the possibility of non-cooperative users. The small sample size of three target users limits the reliability of any results extrapolated from this experiment.

Liberi [37, 38], a networked video game aimed at young players with cerebral palsy, investigates the potential of online games for promoting social engagement among players with disabilities. This game was the product of a 12-month-long participatory design process involving teenagers with cerebral palsy. Though cerebral palsy is classified under the neurodivergence umbrella, its main effects pertain to mobility and fine motor skills. Players use an adapted stationary bike and traditional game control to move their avatars through the online environment, playing mini-games and earning rewards they can trade for in-game items. Designers created mini-games with varying mechanics to balance players' skills and cater to different playing styles. Play-tests involving ten teenagers with cerebral palsy determined that the game was engaging and promoted social connectivity. The authors highlight design recommendations for games aimed at players with cerebral palsy, such as reducing the consequence of errors and balancing rewards based on effort.

With a focus on the inclusion of users in the design process, Piper & Morris [39] detail the design process of a collaborative tabletop video game to promote group work among neurodivergent adolescents: *SIDES*. This four-player game functions on a DaimondTouch table, which restricts and allows interaction from each player ensuring turn-taking and equal decision-making participation. *SIDES* is a motivation and support system, facilitating a space for the natural development of social skills. This project took place over six months, integrated into group therapy sessions. The participants included a group of teenagers aged 11 to 14 and their therapists. The research team employed participant observation and group and individual interviews to understand the needs and goals of the target population. *SIDES* showed promise in fostering the development of social skills and facilitating group work, though the results regarding computer-enforced rules were mixed. The authors present a list of design lessons stemming from this project. They point out tabletop technology as a promising platform for developing educational and playful tools for this population. Computer-enforced rules have a strong advantage over human-enforced rules as they do not require stimuli from another social interaction to facilitate gameplay. However, an adult should be present to observe and lead post-game reflections. The embedding of turn-taking and joint decision-making behaviours in the game proved to help moderate more dominant players. Finally, the researchers point out the importance of helpful schools, parents and therapists and the need for flexibility and adaptability within the design process.

3.1.3 Games for Neurodiverse Groups

To achieve inclusivity, we must go beyond creating accessible games for NT or ND users and move towards inclusive game design. This section describes articles on the creation of inclusive games for neurodiverse groups of players.

To explore play as a vehicle for positive relationships within a diverse group of children, Holt et al. [40] report on the participatory design of several games for neurodiverse play. Through cooperative inquiries, the researchers sought to understand the opportunities and barriers to inclusive play rather than create an inclusive toy or game. Twenty-two children, six with disabilities, participated in the project. Four children were diagnosed with cerebral palsy, one deaf child, and one with dyspraxia. The school grouped the children into "friendship groups", with three to six children each, including at least one child with disabilities and one without. For the initial interviews, the researchers asked each friendship group about their play preferences and experiences with exclusion and to develop ideas for inclusive games.

Children without disabilities tended to balance games in order to support the needs of their colleagues with disabilities. However, children with disabilities showed a desire for challenging games manageable within their ability. The researchers allowed children to test low-fidelity prototypes of the games they had proposed and noted their feedback. The team then refined these into fully functional prototypes and evaluated them with the children. The authors note that design decisions, such as allowing for a variable number of players and embedding social behaviours like cooperation within the gameplay, allowed for more inclusive games beyond accessibility. The article presents an early stage of the project, limited by the lack of a final prototype refinement and evaluation and the need to analyse video data collected from the previous stages.

Sobel et al. [22] present the evaluation of *Incloodle*, an inclusive two-player picture-taking tablet game designed for neurodiverse pairs of children. The app would give the players prompts to photograph collaboratively. The project's main goal was to support interactions between ND and NT children, focusing on themes relating to emotions, socialisation and personal stories. The team developed four conditions, varying in the presence of narrative structure and computer-inforced collaboration. The authors set out to understand what constitutes inclusive play and how technology can support this kind of play. To test *Incloodle*, the researchers recruited 20 children aged 4 to 7, with a 50/50 split between ND and NT. Each pair of children included both a ND and NT child who did not previously know each other. Results showed that children preferred the conditions without technologically-enforced collaboration as this condition was the most restrictive. The presence of characters in the picture prompts aided the participants in connecting with their playmates and modelling emotional behaviour. When the technology-enforced collaboration was present, children were unable to mischievously ignore the prompt, even if they took that decision together. However, this feature was a much-needed equaliser in pairs that struggled with cooperation. The children's newness to each other and the unfamiliar setting may have influenced the results.

Highlighting the importance of play for education and development, and the lack of inclusive play experiences and its impact on the development of ND children, Marti et al. [41] set out to develop and play-test an inclusive educational game themed around archaeological exploration. *Archeo* consists of two wooden puzzles, a classic flat one with a story told through comics and a three-dimensional one recreating a bowl fragment found at an archaeological site. Thirty-three 8-year-olds, six of whom were ND, tested *Archeo* in a classroom context. When creating groups for the testing session, at least one ND child was part of each group to validate the inclusivity of all play conditions. Children reported enjoying the game and displayed cooperation skills regardless of cognitive ability. The research team highlights positive feedback from educators and the importance of the tangible nature of the game. Overall this activity promoted inclusion in the classroom and play-based learning. Researchers did not gather information on the socialisation potential of *Archeo* beyond educator feedback.

Frauenberger et al. [42] report on three case studies relating to the participatory design of social play technologies with and for neurodiverse children. The authors provide a reinterpretation of traditional participatory design approaches focused on the specific user group and a methodological analysis resulting in design guidelines for further research in this scope. This study took place within the context of inclusive primary schools, including three groups of children 7 to 12 years old. Once the group reached a concrete concept, the researchers developed a high-fidelity prototype, which the children tested. All design solutions focused on open-ended social play. As for design insights, the research team gives the following six insights: Children desire complex play experiences where they have control of the plaything. The balance between flexibility and structured activities in participatory design is hard to find; however, the tangible nature of the research prompt offered a good level of both. It is crucial to allow breaks and detours from group work, especially when dealing with ND children. Furthermore, allowing children to find their comfort level of interaction by providing alternative activities will lead to a safe and fun experience. Social playthings should behave in a way that prompts children to interact with them intuitively. The children preferred prototypes that react to user interaction more vividly. Despite the satisfactory results, the authors point to a need to refine the final prototypes.

3.2 Neurodivergence and Robots

The growing trend of Social Robotics has led to research indicating positive affordances of HRI scenarios. This section reports on HRI studies involving ND individuals.

Battista et al. [43] explore the potential of robotic educational activities for special needs education through a survey of 337 educators taking part in a specialisation in Special Education. The participants took part in a course on the educational opportunities of various off-the-shelf robots according to specific age groups. Following, they completed a survey on the potential of robotic learning activities for fifteen different special needs user groups. This study contributes large-scale empirical data on educators' opinions on the use of robots in learning activities. The majority of participants found robotic learning opportunities useful for special needs students and were interested in implementing them in the future. Teachers believe students with ADHD, ASD and dyspraxia, in that order, would benefit the most from such activities. The results varied depending on the specific school years, with kindergarten teachers referring students with psychological and emotional disorders as other likely beneficiaries. Limitations of the research include uneven educator distribution between educational levels and gender. The surveyed teachers only received a short introductory course on learning opportunities of robotic toys. Their lack of experience applying such methods to real-world classrooms could incur further biases.

Within the context of the COVID-19 pandemic, Kewalramani et al. [44] investigate the potential of using AI-powered robotic toys to develop social and emotional skills among young children in a home setting. The authors explore the usability of robots in combating social isolation in children of diverse needs. Five children, three from immigrant families and two ND, alongside their families, participated in a remote study. This study consisted of a workshop (delivered through video conferencing), an at-home trial with the robots, and a final assessment. The research team provided the families with robotic toys: Alpha Mini, Coji, Qobo and the LegoBoost Bot. The authors collected data from Zoom session recordings, videos recorded by the families and drawings generated by the children. The play opportunities afforded by the robotic toys facilitated social and emotional actions from the children. They exhibited behaviours such as collaboration, turn-taking and joint attention. The presence of robots motivated the children to practice skills such as emotional self-regulation and resilience. The experiment is a proof of concept for the viability of robotic toys to develop social and emotional skills among children with diverse needs. However, the limited sample size does not allow us to generalise the conclusions.

Balasuriya et al. [45] research the potential of interaction between social robots and adults with intellectual disabilities. Through semi-structured interviews and the observation of five different workshops, the research team aims to evaluate if and how these robots can support collaboration and engagement in groups of ND adults. The researchers collaborated with a day centre for individuals with intellectual disabilities to recruit six participants who were familiar with each other. The majority of participants were male with a diagnosis of intellectual disabilities, one participant had Down syndrome, and another ASD. Two support workers from the centre also participated in the study as interviewees. During the 45-minute workshops, participants played games with a Cozmo robot while being recorded. Cozmo was successful in inspiring cooperation among players. They asked each other for help, commented on the game and taught others when they had more knowledge. Participants also showcased competitiveness by celebrating wins and showing disappointment when losing. They showed an overall positive affect toward Cozmo, particularly when it called them by their name. However, researchers noted difficulties in turn-taking, understanding and recalling game rules and communicating with other players. Participants expressed the desire for a more talkative Cozmo and anthropomorphised the robot, attributing autonomy and emotions to it. As the sessions progressed, participants seemed more and more engaged with Cozmo; therefore, the authors rejected the impact of novelty in the study results. Cozmo was a valuable tool in motivating the players. It encouraged social interaction among players.

Attempting to leverage the natural interest of students with ASD in STEM fields to motivate learning and skill development, Knight et al. [46] evaluate a model-lead-test strategy for teaching a primary schooler with autism to perform complex tasks using a robot. The child participant was ten years old and, besides autism, was diagnosed with ADHD and an emotional behaviour disorder, often showcasing antisocial and disruptive behaviour at school. The student received solo coding lessons using an off-the-shelf Ozobot. These are small-scale robots with optical sensors at the bottom, which can follow tracks (usually drawn or printed lines) and respond to multiple colour codes within those tracks with differing behaviours. The researchers modelled three tasks using their materials: calibrating the robot, drawing tracks and coding. Then, they guided the student through the task. Finally, they tested his knowledge of the topic. The student acquired and built upon all proposed skills by creating new code examples. No reports of misbehaviour occurred during the coding sessions. Though the small sample size limits the study, it shows promise in using robotics and STEM to motivate students with autism.

Laurie et al. [47] investigate the interaction between children with ASD and tangible robotic or non-robotic toys. To understand whether or not robotic toys improve engagement in this population, researchers observed children playing with a Code-A-Pillar robotic computational kit and a similar wooden toy made up of magnetic blocks. Seven teenagers with autism took part in the study. Some pairs of children received a single toy, enforcing collaboration. In contrast, others received two toys and were free to choose whether or not to play together. From a detailed video analysis of the sessions, the authors conclude that teenagers with ASD were more likely to engage in collaborative play when the presence of a single toy enforced it and when it involved a robotic toy. These findings indicate a potential for using robots to encourage social interaction among individuals with autism. However, the differences between the two toys and the small all-male sample limit the generalisation potential of this work.

3.3 Participatory Design

This section characterises PD and presents different strategies, frameworks and methods to foster creativity and inclusion in PD processes. These mainly focus on methodologies developed for children, neurodivergence and mixed-ability to inform our CD process.

PD is the field of Design characterised by user involvement in the design process. This discipline of user-centred design argues that the only way to understand user needs is to have them as active participants in the development of solutions [48].

This user involvement can come at various stages in the development cycle and have different degrees of impact on a design project [48]. Druin [49] classifies these levels of involvement into four roles: user, tester, informant and design partner. Users are the intended target of a design product, whose needs and desires the design team attempts to fulfil through indirect methodologies, such as theoretical research. Testers are users who provide feedback on design artefacts. This feedback informs the design team on future iterations of a product. Informants establish an open dialogue with the research team throughout a project, providing ideas and feedback. Lastly, design partners are users who become part of a design team during a specific project, making decisions on product development and taking ownership through co-creation.

CD is a specific form of PD in which users are design partners. Though the term is sometimes used interchangeably with PD, CD specifically refers to user participation in all stages of the design process.

It encourages the joint creativity of designers and non-designers to formulate new and innovative products created through UCD methodologies. In this process, the designer's role is to support the user's expertise and passion for solving their design problems by providing methodological support [50].

Druin et al. [51] highlight the importance of including children in the design process of artefacts geared towards them, discussing applicable methodologies. The focus of the research is children's technology outside the educational sphere. The first method explored is Contextual Inquiry, which consists of researchers observing the users partaking in usual activities and asking clarifying questions to uncover their mental model. For applying this method to children, the authors note some modifications. Researchers should avoid notetaking as it can give the children the perception of an evaluation, causing unnecessary anxiety. The authors found several challenges regarding recording interactions, such as children performing for the camera, poor sound quality and difficulty placing cameras. Researchers should attempt to blend into their environment, wearing casual clothes to foster open relationships with participants. The following method, Technology Immersion, calls for the exposure of children to various technological artefacts and gadgets to foster creativity and innovation. This method challenges the children's lack of frequent access to technology by giving them a surplus of opportunities to explore it without being limited by time or sharing it with others. The non-restrictive activity allows children to make choices regarding their use of technology. Finally, the authors discuss Low-Fidelity Prototyping, a method where children directly impact design decisions through craft-like activities using low-tech tools. This method allows children freedom and creative control over their creations.

Expanding on the traditional notion of proxy design, Metatla et al. [23] explore an expansion of this method as a tool to aid children in designing for other children with needs different from their own. The main contribution of this study is Expanded Proxy Design as an approach to co-design methodology. Expanded proxies, within the context of this study, consist of embodiments of the design stakeholders through plush toys introduced with a simple backstory. The authors conducted three case studies to test the validity of this method. In one of the case studies, researchers invited children with mixed visual abilities to design a navigation system for two plush aliens who were temporarily visually impaired. This experiment significantly empowered the visually impaired designers in the group to take the lead and propose solutions from their own experience. It allowed their sighted counterparts to empathise with them and better understand their needs and capabilities. This technique shows promise for mixed-ability co-designing as it invites children to consider the needs of their differently-abled peers without unnecessarily highlighting these children. Unlike traditional proxy design, this method is less open to designer bias, as the research team crafted and controlled the proxy. The main limitation of this study is the lack of coverage of the case studies. The limited testing contexts of the design methodology do not allow us to generalise its employability.

Benton et al. [52] present a framework for including neurodiverse children in participatory design:

Diversity for Design (D4D). This framework does not present specific methods but a means to adapt existing methods for a specific context. This adaption should be done on a case-by-case basis to accommodate for the diversity of ND individuals. To solidify the validity of this framework, the authors present two case studies where it was successfully employed. The authors emphasise the strengths associated with conditions under the neurodivergent umbrella, highlighting creativity as an overarching characteristic. Creativity is also a crucial factor in PD and should be leveraged by researchers. PD projects will empower ND children to make meaningful design contributions by focusing on this and other strengths and crafting design activities accordingly. The D4D framework has four main principles: "Understanding Culture", "Tailoring to the Individual", "Structuring the Environment", and "Providing Supports". The first deals with understanding the typical characteristics of individuals diagnosed with the conditions with whom the team will interact. The second dives into the personal level, understanding the interests, personalities and skills of individual children participating in the design sessions. Thirdly, the research team should adapt the environment where the design sessions will take place to minimise triggers and stress for the children. Lastly, researchers should build individualised supports within each activity to fit each child's needs. Using this framework to plan and structure the design sessions, researchers increase their ability to harness the talents and strengths of ND children.

Building on the traditional storyboarding method, Moraveji et al. [53] propose Comicboarding, an adaption of the traditional storyboarding method geared toward children, and its evaluation. The authors point out that typical PD and User-centred Design methodologies, such as storyboarding, require expression skills often out of reach to young users. Such methods may unintentionally skew data toward the opinions of a few precocious children who can take full advantage of them. Comicboarding builds upon storyboarding by presenting the users with a semi-filled-in comic strip instead of a blank piece of paper. Cartoon characters and motifs familiar to the children add further motivation to the brainstorming sessions. The researchers tested the method with 17 Chinese children, who usually struggle with creative processes due to cultural norms. Children found comfort in the familiar framework and elements of the comics and generated more ideas. The team formulated a variant of comicboarding, magicboarding, where the drawings "magically" appeared at the child's command. Although this method did not yield better results than comicboarding, it surpassed traditional storyboarding. While the proposed method led to more ideas, children tended to stick to ideas already in comics they had read, limiting their creativity.

Guha et al. [54] propose a model for the inclusion of special needs children in design research. This model proposes that researchers carefully consider the "level of involvement" of a child in a particular project taking into account the child's disability and need and availability of support. The researchers combine previous research involving children with disabilities in design with inclusion practices from the educational domain to establish it. The authors highlight the importance of involving children in the design process. However, this involvement should be adapted depending on the specific child. To determine the appropriate role for a child with disabilities, the authors first evaluate the nature and severity of the disability, meaning what barriers stand in the way of involving the child in the design process. Following, they consider the availability and intensity of support, meaning how might they work around those barriers. The ideal outcome of this evaluation is a solution that allows researchers to empower children with disabilities as design partners. For this purpose, the authors describe a method called Cooperative Inquiry. Stemming from PD principles, Cooperative Inquiry is specifically crafted to include children as design partners and has proven effective in including children with disabilities. This method encourages researchers to guide children in CD activities, not for the specific purpose of producing design artefacts but as a way of drawing insights from their behaviour and interactions. Support is critical when adapting Cooperative Inquiry practices to children with disabilities. Some examples of this support include: offering to write what a child dictates instead of forcing them to write their thoughts and offering children the freedom to move wherever they need to complete a task.

Inspired by Speech and Language theory methodologies, Wilson et al. [55] propose a framework for co-designing with children with limited verbal communication: Co-Design Beyond Words (CDBW). The researchers aimed to understand how to support social play in minimally verbal children through tangibles and give them agency in the design process. The article describes the validation of this methodology during the co-design of *TangiBall*, a toy prototype. This methodology relies on the central concept of "moments of interaction", minute social interactions, such as joint attention, turn-taking or imitation. By observing and counting moments of interaction, the researchers can gauge the children's social engagement in tasks within the co-design activities. CDBW consists of Foundation, Interaction, and Reflection phases. During the Foundation Phase, researchers prepare for interaction by integrating themselves into the children's play environment and observing their interactions. The Interaction Phase is where the co-design activities take place. Researchers also apply reflection-in-action during this phase, taking into account moments of interaction and attempting to support them or reworking activities to encourage them. Finally, during the Reflection Phase, the team takes part in reflection-on-action, an evaluation of the previous interactions and how to support moments of interaction in future sessions better. CDBW successfully supported the design process, allowing children to express their opinions towards each other's work and the researchers' suggestions in a non-verbal way, proving the model's effectiveness.

Malinverni et al. [56] present a new framework for evaluating participatory design activities based on user empowerment. This framework, explicitly aimed at design processes involving children with special needs, considers both the creative output of each session and the engagement of child design partners during the session. The authors present the participatory design process of a KINECT game with and for children with ASD as a practical example of this framework. This game was developed throughout five design sessions, preceded by interviews with experts, and aimed to support communication and socialisation among its players. Researchers developed several participatory design activities, such as the personalisation of avatars, role-playing, storyboarding and low-fidelity prototyping, to promote ideation and enjoyment. The team continuously evaluated these methods. When the activities planned for a session received negative implicit or explicit feedback from the children, designers quickly adapted them through within-session adjustments. Researchers and a psychologist analysed video recordings after a session, optimising the next session plan through between-session adjustments. The authors highlight the positive influence of crafting a narrative between the design sessions as a form of continuity. The balance between structure and freedom provided by this detail allowed children to make meaningful contributions with the right amount of guidance. Personalised storage boxes for tangible artefacts of the design process gave the children a sense of continuity and accomplishment. Overall the evaluation methodology successfully created practical and enjoyable design sessions. However, the limited number of participants does not allow for generalising results.

In an earlier publication related to the same project as [42], Frauenberger et al. [57] describe methods for promoting constructive disagreement within co-design sessions with neurodiverse children. The authors highlight the challenge of managing heterogeneous opinions when designing with diverse stakeholders. The article details constructive and destructive disagreements observed in the design sessions as methodological evaluation. To promote contributions from all children, the designers customised individual and group design activities to each child's needs and preferences. Within group activities, children could choose between different roles to accomplish a task. Conflicts arose from three main interaction points: interaction between a child and a design task, interaction among children and interaction between a child and the research team. The authors highlight the importance of reacting proactively to these conflicts. The designer's role is to guide disagreement to a constructive resolution, proposing a middle ground or allowing for individualised options when a consensus is not essential. By allowing children to reshape the design process, designers can achieve their ideation goals and reevaluate their participatory design methodology. Through flexibility and empathy, the participatory design process generated design artefacts promoting enjoyable social play among the children.

3.4 Discussion

From section 3.1, we understand what makes up a game and what elements must result from the Game Design Process. When co-designing a game, we crafted CD activities so as to output the same elements.

Table 3.1: Summary of Analysed Games

Paper	Users	User Involvement	Technology	Goal	Context
[30]	Children Mixed-Ability Motor Disabilities	Informants	Custom Tangible Interfaces and AR	Social Play	Classroom
[42]	Children Neurodiverse	Design Partners	Multiple Custom Tangible Interfaces	Social Play	Classroom
[35]	Adults Mixed-Ability Visual Impairments	Testers	Computer Application	Inclusion	Home
[31]	Children/Teens Mixed-Ability Motor Disabilities	Testers	AR Projector and Sensors	Inclusive Play	Sports
[31]	Children/Teens Mixed-Ability Motor Disabilities	Testers	AR Projector and Sensors	Inclusive Play	Sports
[40]	Mixed-Ability Motor Disabilities	Design Partners	Kinect	Understanding Inclusive Play	N.D.
[56]	ND Teens	Informants	Kinect	Social Skills Development	N.D.
[41]	Children Neurodiverse	Testers	Tangible Puzzles	Inclusion and Play-based Learning	Classroom
[14]	Children Mixed-Ability Visual Impairments	Design Partners	Ozobot Robots	Fun and Inclusion	Classroom
[39]	ND Teens	Informants	DaimondTouch Tabletop	Social Skills Development	Group Therapy
[37, 38]	ND Teens	Design Partners	Computer Application	Social Play	At-Home
[58]	Children Neurodiverse	Testers	Tablet Application	Support Mixed-Ability Interaction	N.D. (in-lab study)
[34]	Children Blind Colour-blind Motor Disabilities	Testers	Computer Application	Educational	N.D
[34]	Children Blind Deaf Motor Disabilities	Testers	Computer Application	Educational	N.D
[36]	ND Teens/Adults	Testers	Android Application	Fun and Physical Exercise	Outdoor Hikes
[55]	ND Children	Design Partners	Custom Tangible Ball Interface	Proof of Concept	Classroom

Table 3.1 shows an analysis of all studies leading to the creation of a game described in section 3.1. From its analysis, we can infer that the level of user involvement in the design process is lacking. Games geared towards mixed-ability interaction between ND and NT children are few, with only Frauenberger et al. [42] employing CD methodology. Furthermore, though HRI research, described in section 3.2,

suggests robots to be a viable and engaging social play opportunity for ND individuals, none of the games analysed utilises robots for interaction with ND players. The classroom context has been widely explored with positive results. Most games aim to incite joy, engagement and social play in players. This may be due to the initial selection of papers excluding entries related to medical models of disability. In this work, we aim to leverage the potential of HRI for the engagement of ND children and apply it to the under-explored scenario of mixed-ability play among neurodiverse groups of children. Furthermore, we employ a CD methodology, giving both ND and NT children much-needed agency as design partners.

Table 3.2: Summary of Analysed Participatory Design Methods

Name	Type	Population	Objective	Limitations
Contextual Inquiry [51]	Method	Children	Observation and Uncovering the Mental Model	Children as Informants
Technology Immersion [51]	Method	Children	Ideation and Creativity	May Create Creative Boundaries
Low-Fidelity Prototyping [51]	Method	Children	Design Ownership and Creative Control	Difficulties in Expression
Expanded Proxy Design [23]	Method	Children	Empathizing with Needs of Different Users	N.D.
Diversity for Design [52]	Framework	Neurodivergent Children	Adapting PD Methods	N.D.
Comicboarding [53]	Method	Children	Supporting Expression in Ideation	May Create Creative Boundaries
Magicboarding [53]	Method	Children	Supporting Expression in Ideation	May Create Creative Boundaries and Bias from the Wizard
Cooperative Inquiry [54]	Method	Children with Disabilities	Drawing Research Insights from Behaviour and Interactions	Lack of Design Ownership
Co-Design Beyond Words [55]	Framework	Minimally Verbal Children	Drawing Design Insights from Behaviour and Interaction	Heavy Data Analysis Workload
Agnostic Participatory Design [57]	Framework	Neurodiverse Children	Supporting Constructive Disagreement	No specific Methodology
Unamed Inclusionary Model [54]	Framework	Special Needs Children	Adapting Design Methods for Special Needs Children	Open to Researcher Bias
Unamed Evaluation Model [56]	Framework	Special Needs Children	Optimising PD towards Efficiency and User Enjoyment	Heavy Data Analysis Workload

Various methods for designing and evaluating are necessary to create successful CD sessions. Table 3.2 summarises the PD methods described in section 3.3. To support children's varying needs, we must balance structured methods, such as [53, 54], and open-ended methods, such as [51]. Some [55, 56] define evaluation methodologies beyond qualitative measures. Others [52, 54–56] pose alternatives for the adaption of CD to the needs of ND users. For this project, we take on the Diversity for Design framework [52], adapting co-design methodologies, such as Technology Immersion [51], Low-Fidelity Prototyping [51] and Expanded Proxy Design [23] to meet our design partners' needs. Methods that heavily rely on researcher interpretation rather than user-lead design, such as Contextual Inquiry [51] and Cooperative Inquiry [54], are not applied, as we follow a CD approach. We base our qualitative analysis on evaluation methods posed by [55, 56], aiming to deliver concrete quantitative results.

4

Methodology & Formative Studies

Contents

This chapter provides an overview of the project's methodology, locating each step in this document and documents the formative studies that informed the conceptualisation of our design process.

4.1 Methodology Overview

The Instituto Superior Técnico (IST)'s Ethics Committee approved the research protocol for all studies within this dissertation, and participants signed consent forms (Appendix A. Many of this dissertation's studies and development processes happened concurrently. We present them in four chapters for ease of reading, grouping activities that lead to combined findings. This organisation does not reflect the chronological timeline of the project. Therefore, in this section, we present said timeline, mapping each activity of the research process to its respective section in this document.

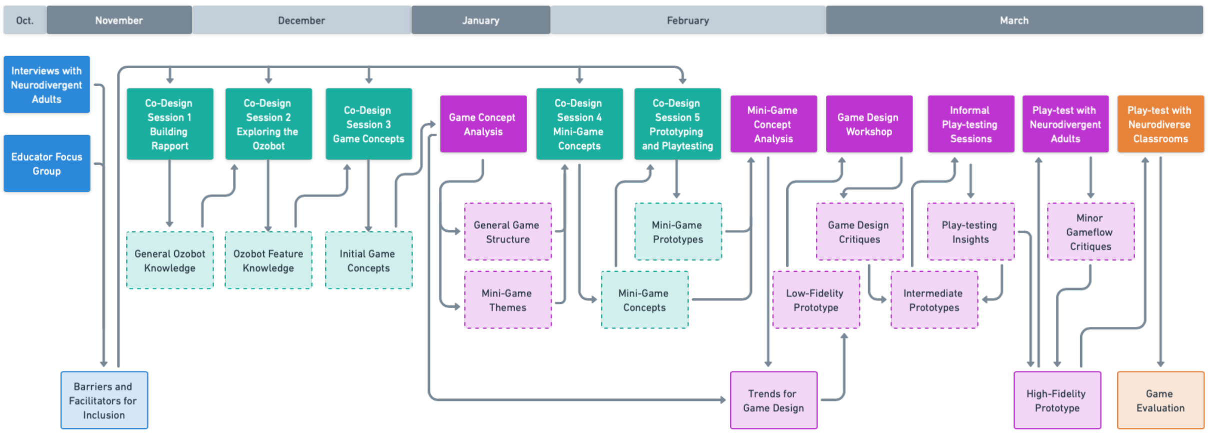

Figure 4.1: Dissertation Timeline Flowchart

Figure 4.1 provides an overview of the process. At the top, in full colour, are the studies, analysis and other activities we conducted in the scope of this dissertation. In the middle row, in pastel colour and dashed outlines, are intermediary outcomes of said activities. At the bottom, in pastel colours and solid outlines, are the contributions resulting from these activities (contributions generated from after-the-fact reflections that had no impact on subsequent activities are omitted). The formative studies phase (Chapter 4) is depicted in blue, the CD workshops phase (Chapter 5) in green, the game design phase (Chapter 6) in purple, and the game evaluation phase (Chapter 7) in orange.

In October and November of 2022, the educator focus group (Section 4.2.1) and interviews with ND adults (Section 4.2.2). From these two studies, we derived a series of barriers and facilitators for the inclusion of ND children in mainstream classrooms (Section 4.2.3). Said findings informed researchers' planning of the CD workshops. From November to December of 2022, we conducted the first three CD sessions (Sections 5.5 to 5.7), which resulted in several initial game concepts proposed by the children. Over Christmas break, we analysed these concepts (Section 6.2.1), distilling a general game structure and four mini-game themes (Section 6.2.1.B). We returned to the school in January and February 2023 for the last two CD sessions (Sections 5.8 and 5.9), which generated concepts and prototypes for the game's mini-games. At the end of February, we analysed these concepts and prototypes (Section 6.2.2), producing a list of trends among them (Section 6.2.3). These trends informed our design of a low-fidelity prototype (Section 6.2.4), which we tested in a game design workshop (Section 6.2.5) in early March 2023. The critiques received in the workshop (Section 6.2.5.A) helped us refine our prototype. Following, we conducted a series of informal testing sessions (Section 6.2.6) through March 2023, each providing play-testing insights that informed changes to the game prototype. Once the prototype was stable, we conducted a play-test with ND adults (Section 6.2.7) and made minor tweaks to the prototype according to its insights. Finally, our prototype reached its high-fidelity form (Section 6.1), and we play-tested it in neurodiverse classrooms (Section 7.2) at the end of March 2023, leading to its evaluation (**??**).

4.2 Formative Studies

Taking on a UCD approach, we first intended to understand the current state of our design scope by engaging with multiple stakeholders. Therefore, we conducted two formative studies to inform our CD process and answer the first research question: **What are the barriers and facilitators to inclusive activities for neurodiverse groups of children in mainstream schools?** Firstly, we conducted a focus group with educators of neurodiverse classrooms, where we fostered discussion regarding inclusion and exclusion in the classroom, accommodations, games and technology. To gather an "own-voices" perspective, we interviewed neurodivergent adults about their childhood, inclusion and exclusion, games, technology and friendships.

4.2.1 Educator Focus Group

Portugal's legislation dictates that all public schools are inclusive, meaning students with disabilities are included in classrooms alongside their peers without disabilities [59]. Neurodivergent students should therefore be placed in neurodiverse classrooms with neurotypical classmates and provided with the necessary accommodations to engage in daily classroom activities. To build rapport with the school staff and understand the barriers and facilitators to inclusion in these neurodiverse classrooms, we first contacted the teachers from Escola Básica das Lopas (the local elementary school where the CD workshops would take place), as they experience this setting daily.

4.2.1.A Participants

We recruited 13 educators from Escola Básica das Lopas. Of those educators, 11 are elementary school teachers (T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, and T11), meaning each is the primary teacher for a single classroom (except for T2 and T8, the school principal and a teacher at the end of her career who plays a logistical support role, respectively), and 2 are inclusive education teachers (I1 and I2), meaning they provide support for students with disabilities of all classrooms.

4.2.1.B Procedure

We held the focus group at the end of the school day in one of the classrooms. The 13 participants and four researchers gathered around a table for the discussion. We introduced our research unit, emphasising our previous work in inclusive education and this project. Then, as an ice-breaker, we had everyone present take turns introducing themselves by sharing their name, profession, experience with inclusive education and a fun fact about themselves. Afterwards, we introduced the concept of focus-group discussion, encouraging participants to build on each others' responses and suggest their related topics.

Over the following 90 minutes, researchers prompted the group with the following questions as discussion starters:

- What is the typical demographic distribution of an inclusive primary classroom?
- How is a typical day structured in an inclusive classroom? How inclusive are the daily activities?
- How frequent and severe are instances of exclusion among children? How are these situations dealt with?
- What role does play play in the classroom? How inclusive are games and toys?
- What strategies are used to promote inclusive play? What toys or technologies are helpful in the process?
- What difficulties exist in promoting inclusive play activities?
- How does technology currently help inclusive play activities?
- How can we embed this activity into the curriculum?

Finally, we showed participants a preview of the next steps in the project and a short demo of the robots later used in the CD workshops.

4.2.1.C Data Collection and Analysis

During the session, the four researchers took notes of key concepts and discussion highlights. Furthermore, with the participant's consent, we recorded and later transcribed the audio from the session. We used a deductive coding approach and created affinity diagrams based on collected data. Two researchers iterated on the codes and categorisation of the data, which were then discussed and refined with the entire team.

4.2.2 Interviews with ND Adults

Secondary stakeholders, such as teachers, parents and caregivers, can provide valuable insights regarding neurodivergent children; however, the lived experiences of neurodivergent persons are the most accurate portrayals of their wants and needs. Conducting interviews with children, especially on such delicate topics as exclusion and as a first introduction, would most likely yield inadequate responses and make them weary of the research team. Therefore, we elicited the help of neurodivergent adults, who can, from a reflective lens, provide us insights into their childhood experiences in neurodiverse classrooms.

4.2.2.A Participants

We recruited six ND adults: three women (A1, A2 and A3) and three men (A4, A5 and A6) (ages 19-52, M=26.83, SD=12.42), two with cerebral palsy (A4 and A5), two with autism (A1 and A6), one with dyslexia (A2), and another with intellectual disability (A3). We partnered with C.E.C.D. Mira Sintra - Centro de Educação para o Cidadão com Deficiência (CECD)[1], a local cooperative that supports people with disabilities in education, employment, housing and healthcare, to recruit three participants (A3, A5 and A6). The remaining participants (A1, A2 and A4) were previous personal contacts of the research team.

4.2.2.B Procedure

We interviewed participants recruited through CECD at CECD's training centre for adults with intellectual disabilities, where they were students. We held the remaining interviews through video-conferencing software. Interviews started with an introduction of the researchers present and the project. Afterwards, we asked participants to introduce themselves, sharing their names, ages, professions and diagnoses. Throughout the interview, we encouraged participants to skip questions they felt uncomfortable with and attempted to match their language regarding disability and neurodivergence. We employed Directive

[1] https://www.cecd.pt

Storytelling [60] to enrich responses. The following questions are a general outline, as the interview was semi-structured:

- Where did you attend primary school? In a special education school or a mainstream school?
- Reflecting on that period of your life, what emotions or thoughts come to mind?
- What was your favourite game as a child? Can you tell me a story of a time you played it?
- Did you have many friends at that stage of life? Where did you make those friendships? Can you tell me a story of a time you played it with a friend in childhood?
- What are the main challenges that exist in inclusion in leisure activities such as games?
- In an ideal world, how would children with neurodivergence relate to and play with others in primary school?
- What is your current experience with games? Which ones do you play? In what context? What barriers do you encounter in them?
- What do you see as the role of technology in inclusion?

4.2.2.C Data Collection and Analysis

During the interviews, the researchers present (one in the case of A1 and A2, and two for the remaining interviews) took detailed notes of the participants' answers. We took audio recordings with their consent, except for A3's interview, as she requested not to be recorded. Through deductive coding, two researchers analysed the notes and transcriptions of the sessions' recordings. Two researchers iterated on the codes and categorisation of the data, which were then discussed and refined with the entire team.

4.2.3 Barriers and Facilitators to Inclusive Activities

As both studies mentioned above served to identify barriers and facilitators for inclusive activities in mainstream neurodiverse classrooms, we combined their findings in the following section. These results served to inform the design of the co-design sessions (Chapter 5) and the game prototype (Chapter 6).

Neurodivergent children are integrated into several classrooms within the school. Eight of nine classes in the school have children accompanied by inclusive education teachers, primarily neurodivergent students. When the school's psychologist diagnoses a child, they remain in their class group with the necessary accommodations. Children with higher support needs (for example, non-verbal or motor impairments) spend most of their schooldays in a dedicated room with the two special education teachers, whom T1 calls *"her 911"*, and they take them to visit their classroom when logistically possible.

T7 noted that *"the students are very used to dealing with difference, they have a special respect for these classmates"*.

Group work promotes inclusion Educators reported that *"what [the children] like to do the most is group work"* (T8). *"The tables are set in groups. So they will see each other's work and interact"* (T1). Furthermore, neurodivergent students *"are included in all the activities that the group does"* (T11) with necessary adaptions (for example, a student with cerebral palsy interacts with a computer using eye-tracking software - T11 - or relating an activity to an autistic student's interest in dinosaurs to motivate him - T1). Teachers perceive neurodivergent students to engage more with materials and activities that break from traditional learning practices. For instance, *"when they get to decide what they are going to do"* (T1) or physical education and art class (T6, T3).

Adult figures, particularly teachers, as models of social interaction for including neurodivergent pupils. Children often followed the teacher's lead as an authority figure, mimicking their treatment of neurodivergent peers. Furthermore, neurodivergent adults who felt excluded in their youth direct most of their resentment towards their teachers, stating that *"this integration has to be done by the teachers, janitors, and staff"* (A1).

Moments of play, such as recess, are the most influential in a neurodivergent child's inclusion. Neurodivergent adults recall these moments as their primary childhood memories of inclusion or exclusion. A6 recalled *"I never used to play, so I did not feel included"*, but A5 stated ''*There were no differences there; whoever wanted to play could play"*. Games are a big part of these moments. In the classroom, *"where [the children] could apply knowledge through games"* (T8), or in recess, where they played football (A4, A5), pretend (A1, A2), and even play videogames (A1). Adults who felt excluded (A1, A3, A6) favoured static single-player games, while those who felt included (A2, A4, A5) preferred dynamic group games. A1 even recalled instances of self-exclusion. However, all yearned for more inclusive play opportunities, specifically enjoyable and accessible games for neurodivergent children and their neurotypical peers.

Technology is a double-edged sword. It is strongly present in today's classrooms. Technological activities are the students' favourites - *"what they like working on now is with the computers"* (T6). However, technology has caused conflict in the classroom - *"those who mastered the tablet very well usually won, he did not, so his groupmates were not very nice"* (T1). Neurodivergent adults recognise that *"technology is important for everyone. For people with disabilities, it is vital"* (A4). Nevertheless, they note that cell phones and individual game consoles can promote exclusion, *"in the old days, we would partner with each other, and we were more comfortable with each other"* (A2).

4.2.4 Limitations

Our formative studies are limited by only including the opinions of secondary stakeholders. Furthermore, as these studies were our first introduction to the teaching staff and half of the ND adults interviewed, participants might not have felt entirely comfortable sharing their experiences. Teachers seemed to attempt to portray the best possible version of their classrooms. Nevertheless, its findings successfully aided the design of CD activities described in chapter 5.

5

Co-Design Workshops

Contents

To answer the second research question, we conducted five inclusive CD sessions at a public primary school: **How to engage groups of neurodivergent children in co-designing inclusive robotic games?** We leverage off-the-shelf golfball-sized robots (i.e., Ozobots [1], Figure 5.1).

5.1 Setting

The CD sessions took place at Escola Básica das Lopas, a local public elementary school. CECD, which provides specialised therapy services at all the local public schools in the area, indicated this school for the project and facilitated contact with the principal. The school is located in a low-income neighbourhood in the suburbs of Lisbon.

5.2 Participants

We worked with four classrooms, two second-grade and two fourth-grade. These were chosen based on teacher volunteering, following the educator's focus group (Section 4.2.1). The teachers who agreed to participate required that their whole classes be included in the project. From heron, each child is denoted as *GXXNNI* (XX - group number, NN - NT or ND, I - within-group identifier). Overall 81 students (43 girls and 38 boys, 6-12 years M=8.22 SD=1.26) participated in the co-design sessions. Nineteen children were diagnosed as ND; 13 had Learning Difficulties (LD) (1 also had dyslexia), 2 with Intellectual Disability (ID), 2 with ADHD, 1 with Trisomy 21, and 1 with Global Developmental Delay (GDD). Detailed information per class can be found in table 5.1, and information per child is available in appendix B. Each teacher divided their class into four groups of 4 to 6 children based on children's interests, friendships, and usual seating arrangement.

	Class 1	Class 2	Class 3	Class 4
Grade	4th	4th	2nd	2nd
Age	9-12, M=9.52, SD=0.81	8-10, M=8.94, SD=0.43	6-8, M=7.05, SD=0.59	7-11, M=7.55, SD=1.01
Gender	13 girls 8 boys	11 girls 6 boys	8 girls 13 boys	11 girls 11 boys
Groups	G01-G04	G05-G08	G09-G12	G13-G16
Neurodivergent	G01ND3 - LD G02ND1 - LD G02ND6 - LD G03ND3 - LD and Dyslexia	G05ND1 - ID G05ND4 - ID G06ND2 - ADHD G06ND3 - ADHD G06ND1 - LD	G10ND5 - LD G11ND3 - LD G11ND5 - Trisomy 21 G12ND1 - LD G12ND3 - LD	G13ND1 - GDD G15ND2 - LD G16ND1 - LD G16ND6 - LD

Table 5.1: Demographics of the classes participating in the co-design process.

Figure 5.1: Ozobot Evo [1]

5.3 Ozobot

The specific robots we used in this project are the Ozobot Evo. This off-the-shelf robot aims to develop coding skills in children and has a plain appearance (Figure 5.1), allowing for more creativity in the design process. Technically, Ozobots possess proximity and optical sensors, allowing them to detect obstacles, follow a drawn line, and respond to a series of colour codes within that line. Ozobots can produce various light effects and sounds. Ozobots can follow lines drawn over a contrasting background and execute specific behaviours, like changing directions, speeds or spinning, upon reading pre-programmed colour codes on said line [1]. Ozobot sells markers intended for drawing these lines [1], and other manufacturers have designed puzzle pieces with the lines pre-printed on them [61]. The Ozobot Evo App [62] provides a remote control function and a block-based programming environment to program the Ozobot [1]. Ozobots have been successful in mixed-ability CD scenarios [14] and in promoting engagement in ND children [46], making them the ideal candidate to bridge the two domains.

5.4 General Procedure

The CD process consisted of five 1h30m sessions over three months. We visited each classroom for each session separately but in the same week. Sessions 1, 2 and 3 occurred in subsequent weeks. Then, we took a six-week break coinciding with the children's holiday break to analyse the results of the previous sessions and formulate an initial design concept. Finally, sessions 4 and 5 took place in subsequent weeks. The groups remained the same for all sessions and carried out all activities together. The class teacher was present in all sessions. Two to three researchers were present for each session, introducing and setting up the activities while observing and facilitating group work among the children.

We started the co-design process by acquainting the children with the research team, their groups, and the Ozobots (Section 5.5), then we encouraged them to explore the robots' functionalities (Section 5.6). With their knowledge of the Ozobots, children started formulating inclusive game concepts using robots (Section 5.7). From analysing these concepts, the research team established a general game mechanic and thematics for four mini-games. Finally, the children created detailed concepts of said mini-games (Section 5.8), prototyped and play-tested them (Section 5.9).

At the beginning of each session, a researcher led the children in a participative recap of the previous

Figure 5.2: Activities from CD session 1. (A) Ozobot decoration kit. (B) Customised Ozobots. (C) Project portfolios.

sessions and introduced the new activities. Each child kept a project portfolio to store worksheets and other materials created throughout the process. All worksheets included pictograms, text, and enough space to write or draw answers, supporting children who struggled with reading and writing (Figures 5.5.B. and 5.7). After each session, the lead researcher wrote field notes reviewed and discussed by the other researchers also present at the sessions.

5.5 Session 1 – Building Rapport

Session 1 aimed to introduce the children to the research team, the project and the Ozobots. The session consisted of two main activities, customising portfolio folders and decorating Ozobots.

5.5.1 Procedure

We began with a short introduction highlighting the project's goal: "Building a game together that you can ALL play together". Then, to build rapport and learn the children's names, we engaged them in an icebreaker, using a foam ball to make its social mechanics explicit. The ball was passed around the class between the students, the teacher, and the researchers. Whoever held the ball told the group their name, age, how they were feeling, and a fun fact about them. The ball was then passed to the next person. In each class, four groups were put together by the respective teacher. To build a sense of partnership and belonging, we asked each team member to fill out a worksheet with their names and a team name.

We decided that each child should have a project portfolio to create a sense of continuity throughout the sessions and give the students a record of them that they can own after the project is finished. Each child was given an A4 folder to house each portfolio. Therefore, to build excitement and ownership around it, each child got to decorate their folder, creating drawings on paper that the research team laminated to the folder (Figure 5.2.C.).

Afterwards, to familiarise the children with the Ozobots, we engaged them in a group crafting activity in which they were given a kit (Figure 5.2.A.) to customise their robot. Each kit contained gem stickers, googly eyes, pompons, sticky tac, pipe cleaners, plasticine, and blank and multicoloured paper. The children were also allowed to use their coloured pencils, pens, glue sticks, and scissors. Each group was given a single Ozobot to decorate collaboratively (Figure 5.2.B.). Their robots were photographed digitally and with a Polaroid camera. The latter's pictures were given to the children, along with a worksheet to preserve the children's work. In this worksheet, children had space to glue their robot's picture and name it. Finally, each group presented their Ozobot to the class.

5.5.2 Observations

Children were generally enthusiastic about the Ozobot and engaged in the crafting activities. The portfolio decoration activity facilitated the child's engagement, sense of agency, and ownership, which potentially could have impacted their intrinsic motivation. Children were highly engaged in cutting, sticking and painting, according to their preferences.

In contrast with this individual activity, collaboratively decorating the robots led to some conflicts. All groups enabled equal participation in the activity, with any instances of exclusion quickly resolved with the teacher's or researcher's support. For example, when G15ND2 withdrew from the activity because his group was not allowing him to place the item he wanted on the Ozobot, the teacher intervened by handing him the robot and establishing a turn-taking mechanic. Children took turns decorating the robot and passing it around the table, satisfying individual preferences and creating a sense of group work. Interestingly, G12 decides, by their own decision or misinterpretation of the task, that each child will create their robot. Although G02ND6 continuously interrupted and misplaced items, G02 collaborated effectively and reached agreements considerate of each other preferences and behaviours, having a pleasant group work experience. Naming the robot proved more challenging, culminating in frustration and negotiation. Some children gave in to a crying groupmate's wishes. In contrast, others reached an agreement through minor changes to proposed names (for example, footballer-inspired "João Felix" became "João" - G13, feminine "Lily" and masculine "Elias" became the full name "Lily Elias" - G14).

Almost all children participated in the presentation activity, proudly showing their customised Ozobot to the class and frequently mentioning what each child contributed. Robots were characterised not only by functionality (for example, "taking samples" - G08, "dancing" - G12, "solving problems" - G10 or "eating" - G15) but mainly by personality (for example, "always smiling" - G12) or aesthetics (for example, "gorgeous" - G10 and "colourful" - G8).

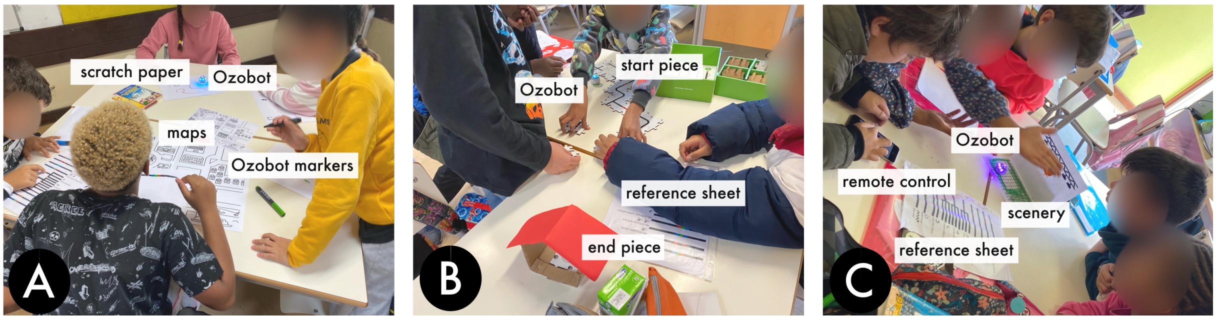

Figure 5.3: Activities from CD session 2. (A) Storytelling activity. (B) Puzzle activity. (C) Dance activity.

5.5.3 Highlights from ND children

All ND children participated in this session's activities, except for G11ND5, whose teacher instructed him to partake in parallel activities. His group ignored him, and the teacher ultimately removed him from the classroom, stating that the child was overwhelmed. G11ND5 was not present in the classroom for the remaining sessions. As the teacher had closely accompanied the child's participation, researchers did not contest his decision to exclude him, assuming he had the child's best interests in mind.

5.6 Session 2 – Exploring the Ozobots

Session 2 aimed to introduce the children to the Ozobot's features and control mechanisms. It was divided into three main activities, a storytelling activity using the Ozobot markers, a problem-solving activity using the Ozobot puzzle [61], and a dance-based activity using the Ozobot Evo App [62].

5.6.1 Procedure

At the start of the session, children were asked to recall the previous session's events. As many had autonomously discovered how to turn on the Ozobot, we asked them to explain how to do it to their classmates. Then we introduced this session's activities. Since two of the three activities are based on the colour code mechanism of the Ozobot, we provided each group with a reference sheet of the main colour codes, which they used as a reference, and to test each code by placing the Ozobot on top of each code.

First, to familiarise the children with the Ozobot markers as a programming tool, children were asked to tell a story about the Ozobot's day. For this, they were given an A2 cartoonish map of a town on which they were asked to create lines with the markers that allowed the Ozobot to go about its day as they told the story (Figure 5.3.A.). An A4 version of the map and black paper were also provided as scratch paper.

Afterwards, to introduce the Ozobot puzzle as another programming tool, children were tasked with guiding the Ozobot home. For this, a start piece was placed on one side of the table and another, inside a house structure, on the other side. Children used the remaining puzzle pieces to unite the two, creating a path for the Ozobot to go home (Figure 5.3.B.).

Finally, to explore the potential of the remote-control feature of the Ozobot mobile app, children were asked to make the Ozobot dance. Each group got to pick their song and decorate paper scenarios to create their ideal dancefloor. The researchers then played the chosen song, and the children used the mobile app to make the Ozobot move to said song and change LED colours accordingly (Figure 5.3.C.).

5.6.2 Observations

Children reacted enthusiastically to the robot being turned on and moving. After watching the robot's first movement, children clapped their hands, cheered and expressed joy and surprise. Using a single robot per group promoted sharing and teamwork through joint attention and physical proximity.

Regarding storytelling, some groups meticulously planned the robot's path, paying close attention to the colour codes. In contrast, others prioritised the story itself without deliberating on the colour codes to guide the robot to the places of the story. Storylines included activities from the children's own lives (for example, going to school or eating at McDonald's) and some more aspirational realities, such as (for example, living in a luxury hotel).

Apart from a few exceptions, children, especially younger ones, did not demonstrate an understanding of using colour codes to guide the robot's path during the puzzle activity. Some took a trial-and-error approach, while others attempted to direct the robot with their hands and verbal commands.

The dance activity was a favourite among the children. In Class 3, when one group began dancing, others stopped what they were doing to join in. During this activity, roles such as choosing the song, decorating the scenery, choreographing the dance, commanding the robot, and choosing the LED's colour were often proactively distributed among group members. Children used voting and timed turn-taking to solve conflicts autonomously.

The various activities allowed each child to use their strengths, leverage their preferences and contribute to the group (for example, G05ND1 took over controlling the robot, while G05ND4, usually quiet, drew on the large map). Many children used anthropomorphic terms to describe the robot's features throughout the session, calling the proximity sensors "eyes" and speaking to the robot. Researchers were able to solve minor conflicts through negotiation. For instance, in G02, G02ND6 disagreed with the group's song choice for the dance activity. With redirection from the researchers, he constructively voiced his opinion by suggesting a singer, and G02NT3 collaborated by choosing a specific song by that artist.

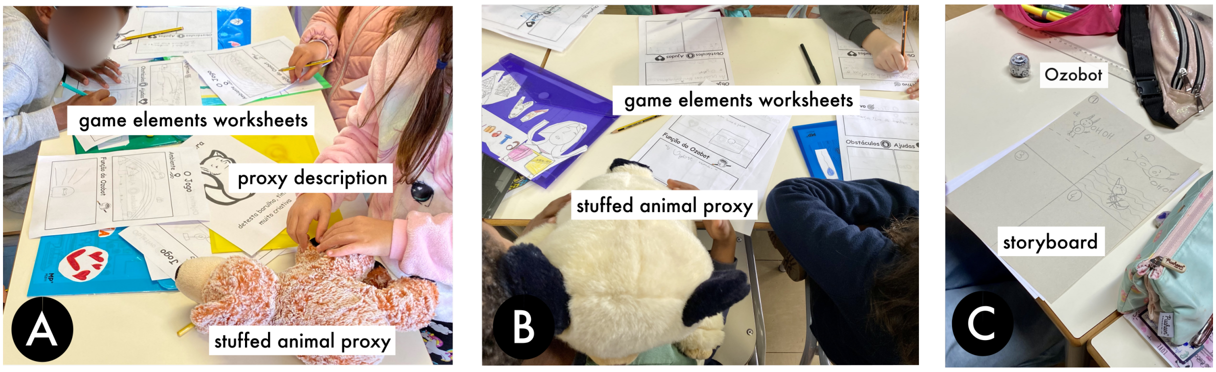

Figure 5.4: Activities from CD session 3. (A/B) Expanded proxy design activity. (C) Storyboard.

5.6.3 Highlights from ND children

All ND children participated in this session's activities without specific accessibility or exclusion concerns.

5.7 Session 3 – Game Concepts

Session 3 aimed to generate inclusive robotic game concepts. This session contained a single activity, which employed Expanded Proxy Design [23] to encourage the children to conceptualise an inclusive game with the Ozobot.

5.7.1 Procedure

Firstly, children were asked to recall the events of the previous sessions. Then they were asked to recall what the goal of the project was. Finally, they were introduced to this session's activity. We scaffolded brainstorming by structuring the activity around commonly used elements in game design (e.g., setting, goal, obstacles, aids). Similar to session 1, researchers had the children pass around a foam ball and take turns sharing, this time about their favourite game. A researcher then used frequently mentioned games to exemplify game elements. For example, in Fortnite, the **setting** is a forest, the **goal** is to be the last survivor, **aids** are medicine boxes, and **obstacles** are other players.

Moreover, to promote the design of an inclusive game without putting the ND children in the spotlight, we employed Expanded Proxy Design [23], introducing each group to a stuffed animal "friend" with specific characteristics (Figure 5.4.A.). These characteristics, communicated in a worksheet with an image representing said animal, mirrored the characteristics of ND group members (Figure 5.5.A). In the case of fully NT groups, the characteristics were tailored to represent the behaviour of any group member that had been used to justify exclusion in previous sessions.

Each group was asked to create a game using the Ozobot for their "friend". During the educator focus group (Section 4.2.1), teachers proposed various curricular themes that could be incorporated into the game. They identified **Oceans** and **Sustainability** as themes they explored at all grade levels. Therefore, to promote convergent design across classes, we set these two topics as a thematic basis for th[e children's games.

Children were asked to fill in a worksheet detailing the game's setting, the Ozobot's in-game function, the game's goal, obstacles, and aids (Figure 5.5.B.) to express their game concepts. Each group was also provided blank paper to create more materials that helped them communicate their concept if they desired. Ozobots were made available for groups to have at their tables and better conceptualise their in-game function. Finally, each group presented their "friend" and game to the class.

5.7.2 Observations

When sharing their favourite games, most children mentioned playground games such as catch, hide and seek, and soccer, as well as online games like Minecraft, Freefighter, Fortnite, and Roblox. Only one child mentioned a board game. They frequently mentioned the thrill of playing games and the satisfaction of winning, especially against skilled players.

The children enthusiastically approached the stuffed animals, especially the panda bear (Figure 5.4.B.). However, some groups had conflicts regarding sharing, which researchers solved using turn-taking. Children's game concepts prominently featured the stuffed animals' traits, for example, a prank-based game for their mischievous monkey - G02.

In addition to the worksheet, many groups created supplementary materials, such as written stories, storyboards, drawings, and diagrams (Figure 5.4.C.). We observed the autonomous division of tasks. For instance, in G07, a child wrote the story, another rewrote it with pictograms, another created a storyboard (or comic strip), and the last drew illustrations.

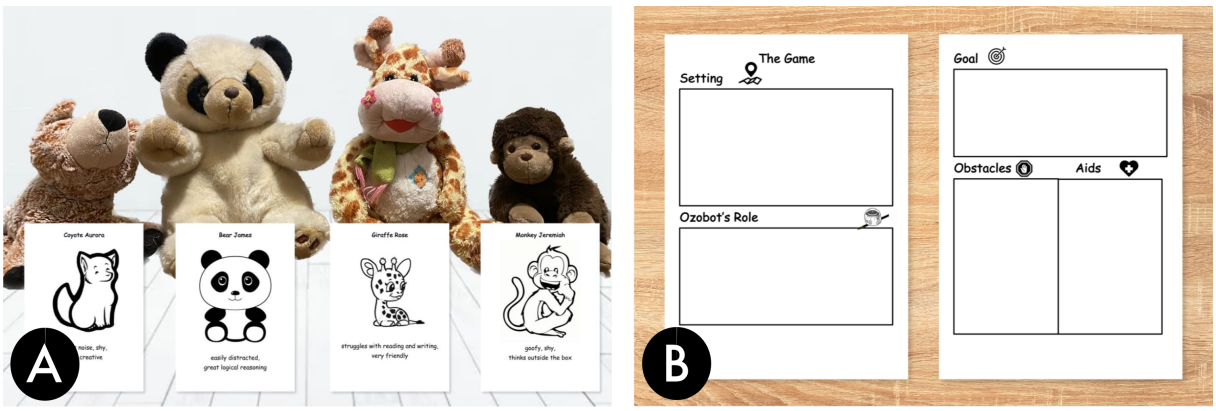

Figure 5.5: Session 3 materials. (A) Expanded proxy stuffed animals and their description sheets. (B) Game elements worksheet.

Figure 5.6: Activities from CD session 4. (A) Group decision-making. (B) Prototyping. (C) Storyboard.

Some groups were uninterested in the broad curricular themes or struggled to formulate them into games, discarding them altogether. Children proudly presented their work alongside their group while affectionately holding their stuffed animals, indicating team spirit. A typical storyline among groups described an enemy polluting an environment and the player character trying to keep it clean.

5.7.3 Highlights from ND children

Two of the 19 ND children verbalised the similarities between the animal and their characteristics. For example, G05ND1 said, "She is like me! [...] She may not be able to read and write, but she has a good heart.". Many ND children initially struggled with the game elements and worksheet concept. Researchers clarified concepts and encouraged them to express themselves through drawings. ND children were very attached to their ideas leading to their groups compromising and merging various ideas to satisfy everyone's taste.

5.8 Session 4 – Conceptualizing Mini-games

After session 3, the research team analysed the children's game concepts and formulated the general concept of a game of catch where the Ozobot would chase the players around a board game while they attempted to complete various mini-games; we detail this analysis in section 6.2.1. Session 4 aimed to generate detailed inclusive mini-game concepts through a single brainstorming activity.

5.8.1 Procedure

At the start of the session, children were asked to recall the events of the previous sessions. Then we caught them up on our in-between sessions work and presented the central game concept. They were introduced to this session's activity and given a run-through of its worksheet (Figure 5.7). Finally, to introduce the concept of mini-games, we brainstormed games that can be played while sitting at the table, with no screens, and in less than 5 minutes.

Each group was given one of the four themes distilled from the children's original concepts, escaping from a shark, sorting trash in recycling bins, finding an underwater treasure, and rescuing animals. They were asked to create a mini-game relating to it. Like in the previous session, children were asked to fill in a worksheet detailing the game's setting, whether or not the Ozobot was part of their game, and if so, how it would be controlled and what would be its function, the game's goal, obstacles, aids, starting point, actions, how one wins or loses and the respective reward or consequence (Figure 5.7). Besides the worksheet, each group was given a gameboard prototype and blank scratch paper to help conceptualise (Figure 5.6.A.). Ozobots were made available upon request. Children were asked not to colour or write on the gameboard and informed that they would be able to do so the following week. Children were asked to fill out a list of necessary game pieces to play their game to help plan the next session. In the end, each group presented their mini-game to the class.

5.8.2 Observations

This session's activity required discussion and joint creation within the groups; this process surfaced various challenges and conflicts. Most groups focused on the story aspect rather than gameplay, and many struggled with the complexity of the worksheet. Researchers solved these issues by redirecting the groups towards drawing and prototyping (Figure 5.6.B.). Additionally, there were instances of successful spontaneous prototyping and collaboration, and some groups overcame language or other barriers to collaborate and create game concepts.

Conflicts emerged due to divergent ideation or disruptive behaviour. For instance, in G06, conflicts arose mainly between G06ND2 and the other members. His ideas diverged from the majority's, and he was unwilling to compromise. The group found his behaviour disruptive, as he fiddled with the board, waved other people's worksheets around, and even crawled under the table. One major conflict arose

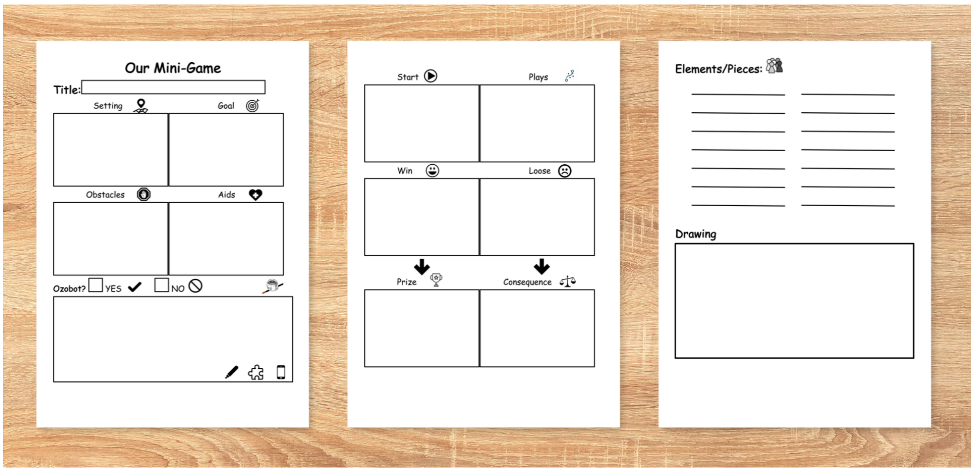

Figure 5.7: Game elements worksheet from session 4.

over the prize for the game, leading to a philosophical debate about what is most important in life - money, health, or family. Researchers elected to allow the group to come to an agreement on their own. Eventually, they reached an agreement; the prize would simply be to live, surviving the shark attack. Due to not having access to his medication, G05ND4 presented with very low energy in this session, making the other group members hesitant to continue without him. With aid from their teacher, G05ND1 took on a leadership role and developed the mini-game's narrative while the rest of the team, including G05ND4, created visuals to accompany it (Figure 5.6.C.). Though their game lacked practical mechanics, they proudly presented it, highlighting G05ND4's contributions.

G12 and G03 created explicit dynamics for turn-taking and egalitarian participation. G12 used a handshake game to determine who made each decision (Figure 5.6.A.). Group members would all chant *"zero or... one!"* and then hold out a hand with one extended finger or their fist closed. They repeated this until one player won by choosing a handshake different from all others. That group member would then get to choose a specific game element, and all others registered this choice on their worksheets. In G03, the members placed their hands in the middle of the table whenever they wanted to speak. Upon seeing their classmate's hand stretched out, group members went quiet and allowed them to share their opinion or concern. Mini-games generated in this session still prominently featured the "catch" mechanic, with some employing sports metaphors, but most concepts were vague. The activity highlighted the importance of teamwork, which needs to be worked on more in the classroom, according to one of the teachers during that session.

5.8.3 Highlights from ND children

Some ND students struggled with the worksheet and collaborative decision-making process. However, due to this session's similarity to the previous one, most had already developed strategies to deal with these points. Strategies, such as those of G03 or G12, allowed for all group members to input their preferences into the group's game concept. And as children grew accustomed to group discussions, disagreements, such as G06's, became spaces for sharing opinions and better understanding each other. Contrasting with NT groups, neurodiverse groups took longer to reach an agreement. However, the concepts generated by the lengthy discussion that ensued were much more detailed.

5.9 Session 5 – Prototyping and Playing

Session 5 aimed to flesh out the children's mini-game concepts through a low-fidelity prototyping activity.

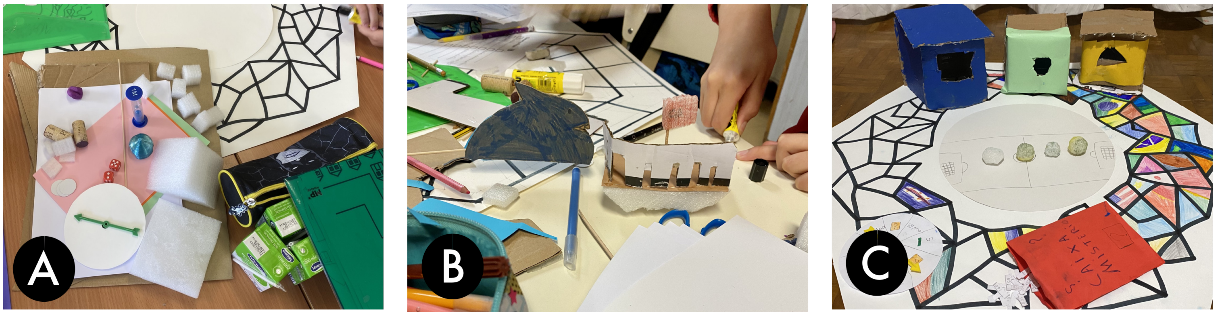

Figure 5.8: Activities from CD session 5. (A) Prototyping materials. (B) Prototyping. (C) Low-Fidelity Prototype.

5.9.1 Procedure

Firstly, children were asked to recall the events of the previous sessions. They were introduced to this session's activity and some general ground rules.

Each group was given a game prototyping kit (Figure 5.8.A.) consisting of a gameboard prototype, a 3D printed Ozobot hat, a few pieces of recycled cardboard, blank and coloured paper, a few blocks of foam in varying sizes, blank construction paper coins, two six-sided die, a spinner with a blank base, a few wine corks, a few wooden skewers, and a sand watch. Extras of these materials were available upon request. Groups who requested specified materials in their lists in the previous session received them, such as the Ozobot puzzle and blank playing cards. Children were encouraged to use their glue, markers, pencils, scissors, and other materials available in the classroom if allowed by the teacher. Two ground rules were established: paint was not to be used as the drying time made it impossible to complete the activity, and the Ozobot's decoration should be done on the provided hat and not the robot itself to preserve their creations. The groups were tasked with creating all the necessary elements to play their mini-game.

When the prototypes (Figure 5.8.C.) were complete, children rotated between groups to test their classmates' prototypes, while some stayed at their tables to introduce the game to their classmates.

5.9.2 Observations

During this session, children had a clearer idea of what they wanted to create, resulting in significantly fewer conflicts. Each child could own and prototype a particular element with the various game pieces.

G16 and G04 had gender-based conflicts, where members of the more predominant gender took over the creative process. Even with researcher encouragement, the games remained as they were. Like previous sessions, G06ND2 had some friction with the rest of the group, but dividing tasks prevented these conflicts from escalating. G11NT4, who did not speak the local language, spent most of the session prototyping game pieces unrelated to the group's concept.

In this session, some children took on more leadership than before, as they felt more comfortable with the group and with a common goal. Regarding play-testing, children showed pride in showcasing their game and curiosity in trying out other's games. Although most games lacked well-defined mechanics, children could play them, improvising new rules as needed.

5.9.3 Highlights from ND children

ND children flourished in this open creation environment, often taking on a single game element and prototyping it in extreme detail, resulting in praise and inclusion from their peers. For instance, G06ND2 created a very realistic boat structure (Figure 5.8.B.), G02ND6 diligently coloured the gameboard, and G16ND1 shaped fishes out of plasticine.

5.10 Discussion

Three researchers, who had participated in the co-design sessions, reflected upon the observational findings and identified the main takeaways through an inductive and deductive coding process. These codes were iterated upon and reviewed by the whole research team. We divide them into two main categories, the mutual impact between the classroom environment and CD process and best practices for co-designing in neurodiverse classrooms.

5.10.1 Reflections on Co-Designing in Classrooms

Findings from the formative studies and our in-class observations during co-design sessions showed the richness and enlightenment of a UCD approach to envisioning challenges for inclusion in classrooms and the efficacy of CD experiences to tackle them. The CD process with children was also iterative, allowing for mutual influencing between it and the classroom dynamics.

The teacher could be a vital factor for including or excluding a ND child. Formative studies identified teachers' behaviour as a barrier and a facilitator for including ND students. By observation of the classroom dynamics, researchers uncovered behaviours from teachers that influence the children's inclusion or exclusion.

First, **teachers offer parallel and individual work to children with higher support needs, which could lead to social exclusion.** Teachers identified logistical issues, such as dedicated time, and lack of human resources, as the main barrier to including them in the classroom. For example, a child with Trisomy 21 (G11ND5) was excluded from the co-design process. He attended the first five minutes of the first co-design session, being encouraged by his teacher towards parallel work rather than group work, not genuinely including him in the process. After this short time, he became restless, and the teacher removed him from the classroom to avoid distracting the other students.

Second, **small group work is not typical in the classroom.** Teachers identified group work as a significant focus in their classrooms. Children sat together in groups, but their lack of experience in collaboration and joint decision-making was evident throughout the co-design sessions. The teacher from Class 3 realised this gap during the sessions, sharing that he had yet to prioritise soft skills such as group work due to the extensive mandatory curriculum. In the following weeks, the teacher from Class 4 made a point to instruct their students on how to work together in a group setting, which strongly positively impacted children and the co-design process.

Third, **teachers attitudes towards children differences influenced their behaviour**. Teachers' personality traits and pedagogical practices greatly influence children's inclusion and respect towards others. A more directive teacher guides the children during the creative process, showing them videos of DIY artefacts needed for the game (Class 3). However, he was also demanding, making children work individually and follow instructions precisely.

In turn, a very affective teacher can coddle the class, even referring to her ND student as *special ones* (Class 2). She claimed children showed a "special respect" towards their "more different" peers. Though her attitude seemed to stem from a caring place, it came off as somewhat condescending. The terminology she used to refer to ND children belittled them. Furthermore, though her constant encouragement of NT students to help ND peers created more empathy among children, it brought extra attention to children she considered "special". This compelled NT students to interact and aid their ND peers, but their motivations to do so were dubious.

Children's attitudes towards neurodivergence. Most ND characteristics are not physical, being interpreted by NT children as mere personality traits. For instance, G06ND2, a child with ADHD, was restless and sought out stimming, which their group mates considered annoying and disruptive. Although we witnessed the exclusion of ND children by their peers, teachers had previously claimed it did not occur. We interpret this as coming from a place of misinterpretation. If a ND child is excluded because of their behaviour, they consider it an ordinary conflict. Nevertheless, the co-design process created a more inclusive environment, promoting empathy and respect even in the most divided groups (G01, G06, G13).

Our approach, based on playful activities, allowed us to discover the implicit challenges of inclusion in neurodiverse classrooms. Children and teachers identified personal differences during the process and acted upon interpersonal conflicts and tensions using novel ways to interact, prompted by our CD process. Moreover, it allowed children to be more empathic and tolerant towards each other, informed teachers of the absence of group work and made them adjust their pedagogical practices.

5.10.2 Best Practices for Supporting the CD of Games in Neurodiverse Classrooms

Our CD practices allowed all children to have a voice in the design and feel part of their group. From our experience co-designing a robotic game with four neurodiverse classes, we present a series of best practices.

Making group dynamics explicit allows egalitarian participation. ND children can often struggle when social mechanisms, such as turn-taking and joint decision-making, are implicit. Passing the Ozobot around the table or using a sand watch to control time effectively facilitated turn-taking. Having an agreed-upon signal for when someone wants to voice an opinion, a system for showing agreement or disagreement towards an idea or luck-based ways to resolve standstills reduced the amount and severeness of conflicts associated with joint decision-making.

Resource sharing promoted shared awareness and group work. Limiting the items provided to each group promotes interaction between group members and creates shared awareness and team spirit. However, this is only true when the items are necessary for the task. When groups receive extra items as inspiration, one child tends to hog them, leading to conflict. On the other hand, when the shared resources belonged to a child and not the research team, sharing was not obvious to the children.

Physical closeness has a significant positive impact on how children interact. Not being able to hear each other or reach shared materials can leave children excluded from a group activity. Having a smaller working table where everything is at arms-length of every child promoted more balanced group interactions.

Hands-on activities were far more engaging than brainstorming and discussion activities. Long periods of sitting still and trying to reach an agreement through debate proved to be fatiguing, especially for ND children. When frustrated, some ND children resorted to stimming, which was not understood by their peers, leading to conflict or self-exclusion. Introducing more tangible and hands-on activities, such as creating sketches and prototypes, into the decision-making process facilitated engagement and creative participation from all group members.

A variety of tasks allows children to take on different roles according to their preferences. Activities should require multiple decisions and or the creation of multiple outputs. When each child can take over a part of the process, and the different tasks happen concurrently, everyone has the opportunity to participate, facilitating the feeling of ownership and pride over the joint final result. This approach leads to more creative freedom for each child, which is particularly important in ND children who might have an easier time actualising in tangible ways.

Making session deliverables explicit through accessible worksheets helped structure the sessions. These worksheets guided them through all the tasks or decisions they had to complete. However, this structuring element was only practical because of its flexibility. Allowing children to write or draw out their answers and using pictograms made the worksheets accessible for those ND children who struggled with reading and writing. Alongside the worksheets, researchers provided the groups with scratch paper where they could plan out their responses and create additional materials, making the worksheet a starting point instead of a limit to their creativity.

Allowing child co-designers ownership of their design artefacts gave them a sense of accomplishment. Making these outcomes tangible for each child to add a copy to their portfolio increased children's motivation. Children were excited to take their creations home to show their friends and family what they had accomplished. Taking away children's work proved detrimental, even if logistically necessary.

Presenting their group's work to the class was a highlight of the sessions. Children showed team spirit, ownership, and pride in their work. Participation was optional, and shyer children initially elected to stay at their table but eventually joined their group in presenting. Groups highlighted each member's contributions at this moment.

Equally destributing the ND children among groups might not be ideal. It might draw attention to these children and make the groups unbalanced regarding friendships and personalities. Allowing the teachers to create groups based on typical group work divisions in the classroom enabled children to use their previous knowledge of each other's working styles, promoting understanding.

Expanded Proxy Design was effective and yielded creative and accessible game designs. This technique helped communicate a complex concept such as neurodivergence to young children without making them feel othered. All of the resulting designs considered the accessibility needs and preferences of their proxies. Children kept these concerns in mind throughout the remaining design process.

Maintaining a sense of continuity through the co-design sessions was crucial. The participative recap at the beginning of each session helped achieve this, rewarding remembrance of previous sessions and bringing them to the forefront. The portfolio also served as a conducting thread throughout the sessions. Children often referred to it to aid in recalling a previous activity.

5.11 Limitations

Firstly, we recognise that neurodivergence is a broad spectrum, as our sample of 17 ND children, all within the same school, only partially encompasses it. Therefore, our findings may not be generalisable for other neurodiverse groups. Other factors, such as the specific socioeconomic environment, gender-based conflicts, the novelty of the robot, the presence of children who were not fluent in the local language and the teacher's involvement style, also impacted the co-design process. Our project focused on including ND children who already spent most of their school day with NT peers in the classroom.

Therefore, our methodology is not inclusive of children with higher support needs, specifically non-verbal children.

6

Game Design

Contents

6.1 The Game: “The Shark Escape”

Based on the game concepts generated through the CD sessions (Chapter 5), we engaged in an iterative design process (Section 6.2), leading to the design of “The Shark Escape”. “The Shark Escape” is an enhanced board game, themed around sustainability and oceans, aimed at neurodiverse groups of three to six players, which leverages robotics and AR to promote an inclusive and engaging gaming experience.

6.1.1 Main Game Mechanic

The game’s central mechanic takes inspiration from the classic recess game of “catch”. Players, represented by marine animal-shaped pawns, move between spaces in the board according to a digital dice (Figure 6.1.B.). Meanwhile, the Ozobot, decorated as a shark, attempts to catch their pawns, moving continuously through the board’s black lines (Figure 6.1.A.).

The player’s pawns start at the yellow spaces along the edge of the gameboard. The Ozobot starts in the middle, rotating randomly to choose a path. All players move their pawns simultaneously, according to the same dice roll, in the direction of their choice. This detail makes it so no player gets caught by the “shark” while waiting for their turn and boosts engagement. The digital dice promotes fairness, not giving any player extra control of this element, and sets the game’s pace, as it rolls automatically every 10 seconds.

To win, a player must reach each of the three mini-game spaces (Figure 6.2.B.) and win at each mini-game, returning to their initial space (the yellow space closest to their seat) with the three corresponding tokens. If a player is caught by the Ozobot, by it knocking against or toppling over their pawn, they must give up one of their mini-game tokens. However, if a player has a life token, they can give it up instead of a mini-game token. If a player has no token, the game proceeds. The “boat” spaces in the middle of

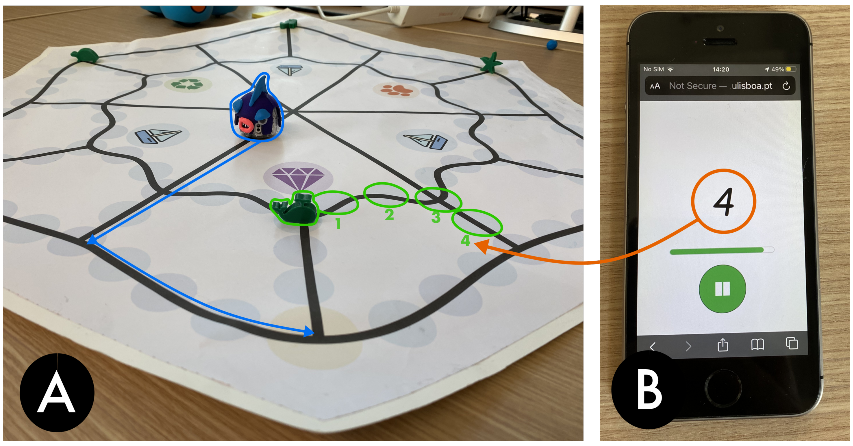

Figure 6.1: Movement of pieces in the gameboard. (A) Ozobot and pawn movements. (B) Digital dice.

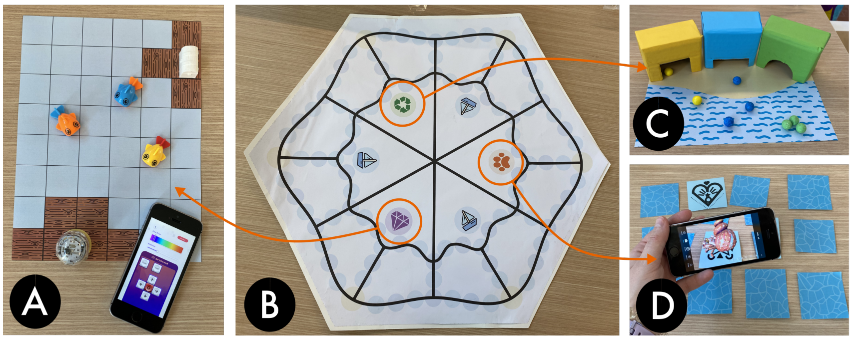

Figure 6.2: Mini-games. (A) Treasure mini-game. (B) Gameboard. (C) Recycling mini-game. (D) Animals mini-game.

the gameboard are safe, as the "shark" cannot reach them. When the players are playing a mini-game, the Ozobot is paused in place unless it is being used in said mini-game.

6.1.2 Mini-Games

The three mini-games combine luck and skill to create a balanced playing experience for all children. Furthermore, they incorporate different player dynamics, technology, themes and skills, catering to the varying interests of their target players. All games are competitive, with each player competing for the game's token. For games where more than one player competes for the token, at least one participant must lose.

Recycling is a two-player mini-game based on fine-motor skills. The player who lands on the mini-game's space chooses an opponent. Each player gets a 30-second, controlled by an hourglass, to sort as much "trash" as possible from the ocean into the correct recycling bin. The trash is represented by yellow, blue and green styrofoam balls, which players attempt to score goals within the recycling bins' opening (Figure 6.2.C.) by flicking it with their fingers as they would a marble. The pieces are placed on an A4 paper with land and sea areas printed. The bins are in the land portion, while the "trash" starts in the sea portion. As players attempt to score if a styrofoam ball lands on the land area, they may not re-shoot it. Players are awarded a point for each "trash" piece in the correct bin at the end of the 30 seconds. The player with the most points wins the mini-game. In case of a tie, no one wins.

Animals is a multiplayer mini-game based on memory and logic skills. All players participate in this mini-game inspired by the classic memory card game. Players shuffle and place the 12 cards facing down on the table. Starting with the player that landed on the mini-game's space, each player takes a turn flipping two cards and attempting to find pairs. Unlike the classic version of the game, all cards are different. The pairs can only be revealed by pointing a smartphone or tablet at the cards, revealing a 3D marine animal on each (Figure 6.2.D.). This mini-game leverages AR through the HaloAR [63] application. Each card is an AR marker linked to one of six open-source 3D models of marine animals.

Using the app, players uncover the contents of each card. When a player finds a pair, by flipping over two cards with the same linked 3D animal, they take said cards off the table, keeping them. The player holding the most pairs wins when no cards remain on the table. In case of a tie, all tied players win.

Treasure is a single-player mini-game based on problem-solving skills. The player who landed in the mini-game's space must control the Ozobot, using the Ozobot Evo app's [62] remote control feature, guiding it to reach the treasure chest. The robot is placed on an A4 sheet of paper with a six by eight grid with designated spots for the treasure chest and the Ozobot start-points (Figure 6.2.A.). These points and surrounding squares are depicted as wooden planks, while the rest of the sheet is covered in blue squares, depicting an ocean area. Before a player starts commanding the Ozobot, the remaining players must set the challenge for them. They are tasked with placing three fish figures on any non-adjacent water square they choose. The player who landed on the mini-game's space has a 30-second window to guide the Ozobot to the treasure without touching any of the "fishes". If they succeed, they win the mini-game.

6.1.3 Rewards

After winning a mini-game, a player receives a mini-game token (Figure 6.3) in a colour corresponding to that mini-game's gameboard space (purple for Treasure, green for Recycling and orange for Animals). Moreover, they can win an extra prize by spinning the lucky prize wheel (Figure 6.3). This wheel has six sectors, corresponding to five possible prizes and one chance to win no additional prize. Possible extra prizes are winning an extra heart-shaped life token (Figure 6.3), winning a colour code sticker (Figure 6.3) or winning a chance to move any piece on the gameboard two spaces. The colour code stickers can be placed over the gameboard's black lines, commanding the Ozobot to complete a specific order when it reaches them, stopping for 3 seconds for the red code or making a U-turn for the blue

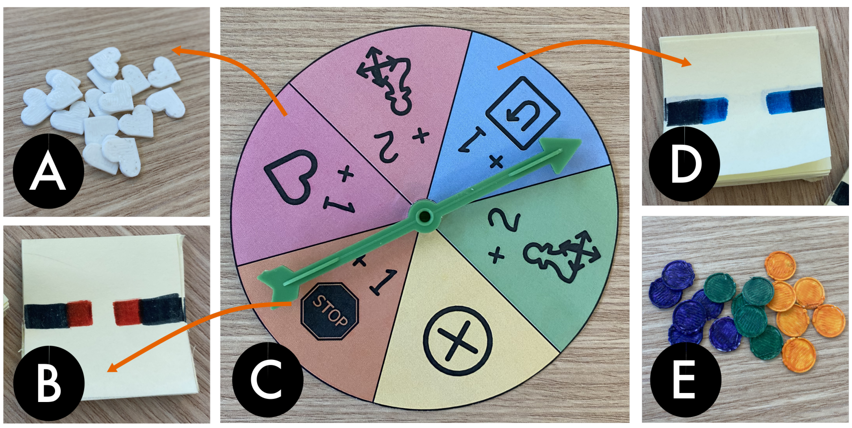

Figure 6.3: Rewards. (A) Life tokens. (B) Stop colour code sticker. (C) Lucky prize wheel. (D) U-turn colour code sticker. (E) Mini-game tokens.

code. Players can place their colour code stickers on the gameboard at any point in the game after acquiring them.

6.1.4 Technical Details

The Ozobot's movement is controlled through two snippets of Ozoblockly [64] code. Using this block-based programming language, the robot's movement can be easily paused and resumed through the Ozobot Evo App [62]. Furthermore, this coding modality allows the robot to remain paired with a single mobile device for the game, switching between Ozoblockly and the remote control function for the Treasure mini-game. The Ozobot's line-following mechanic is very similar to its default behaviour. It follows a line up to an intersection, randomly selecting which direction to take. However, by using Ozoblockly, we had to build this behaviour into our code and a new colour code mechanic since the Ozobot cannot access these functions while running custom code. The main code snippet used in the game is depicted on Figure 6.4.

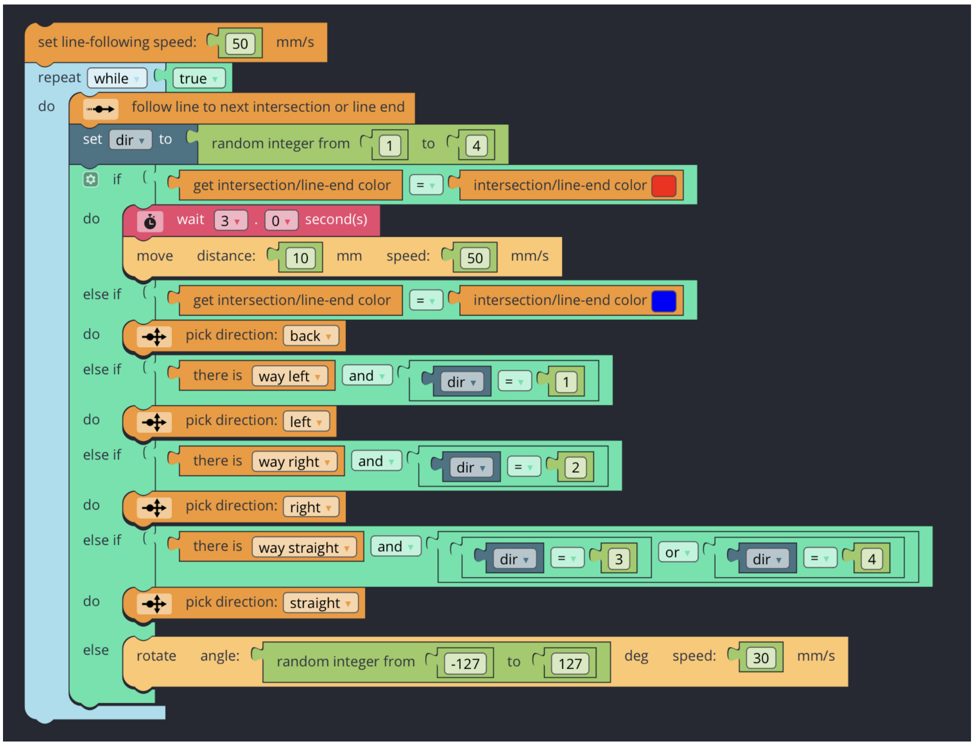

Figure 6.4: Ozoblockly "go" code snippet

6.2 Iterative Design Process

In sessions 3 (Section 5.7), 4 (Section 5.8) and 5 (Section 5.9) of the CD process, children generated game concepts and prototypes. This section details the analysis of said prototypes and the iterative process of crafting insights from said analysis into the fully-fledged game described in Section 6.1.

6.2.1 Initial Game Concepts

At the end of the third CD session, described in section 5.7, each of the 16 groups of children participating in the project crafted a game concept.

6.2.1.A Data Collection and Analysis

Researchers photographed the children's worksheets during the session and video-recorded their presentations, gathering these two data sources into a single digital whiteboard. Afterwards, one researcher analysed the children's concepts through inductive coding. The whole research team reviewed the generated codes.

6.2.1.B Findings

From the 16 game concepts, we identified **"catch" as the predominant game mechanic** (10 of 16 concepts). Concepts revolved around reaching a narrative end goal while avoiding being caught by an enemy, for example, returning a lost panda bear to its family while avoiding being caught by hunters (G03). Other mechanics included collecting items, such as trash (G07, G08), scoring goals (G13) and escaping a labyrinth (G09).

We found **a preference towards games with a variety of in-game tasks** (9 of 16 concepts), for example, completing winning at UNO and walking a dog (G05) or collecting trash (G03) while racing not to get caught. However, we did not find an overarching narrative theme among the games and did not want to limit the co-design game to the majority's preferences. Therefore we established "catch" as the main game mechanic, with the Ozobot chasing the player's pieces around a gameboard, but promoted the inclusion of divergent ideas through the design of 4 mini-games, that players would have to complete upon landing on specific spaces in the gameboard.

Nine of 16 concepts were related to the curricular themes. From those, we extracted the four mini-game themes: recycling (3 of 9 concepts), rescuing animals (2 of 9 concepts), escaping from a shark (1 of 9 concepts) and finding underwater treasure (1 of 9 concepts).

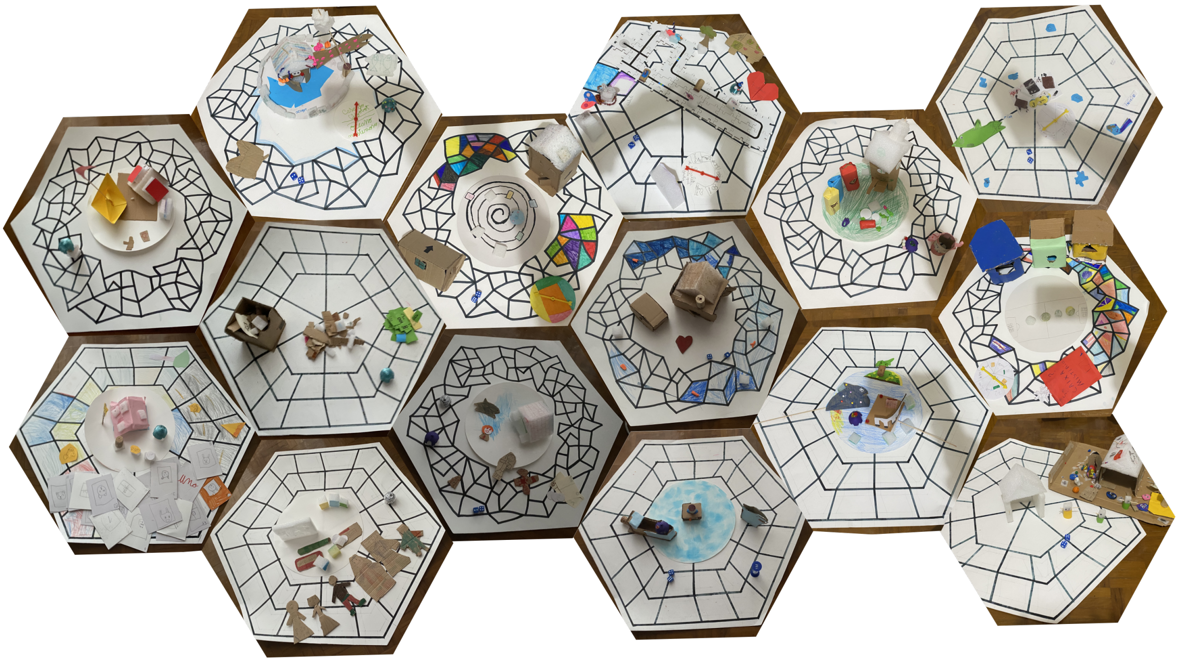

Figure 6.5: Children's prototypes from CD session 5.

6.2.2 Mini-Game Concepts

The four mini-game themes identified in section 6.2.1.B were distributed among the groups in each classroom. During sessions 4 and 5 of the CD process, described in sections 5.8 and 5.9, each group created a game concept and prototype for their assigned theme, culminating in four prototypes per theme (Figure 6.5).

6.2.2.A Data Collection and Analysis

During the sessions, researchers gathered pictures of the children's worksheets, sketches, and videos of them presenting their concepts and play-testing their prototypes. The research team collected each group's prototypes and photographed each in a neutral environment. We gathered all pictures on a digital whiteboard, where researchers conducted a deductive coding process while examining the physical versions of the prototypes. Each prototype was coded for the group's primary focus during construction, ideas, helpful concepts, and game mechanics. Two researchers iterated upon the codes, which were reviewed by the entire research team.

6.2.2.B Findings

In the second batch of game concepts (i.e. mini-game concepts), we identified the following reoccurring ideas: fish as obstacles (3 of 16 concepts), boats as safe spaces (3 of 16 concepts), sports-inspired recycling mini-game (3 of 4 recycling concepts), hearts representing lives (2 of 16 concepts) and cash-like victory tokens (5 of 16 concepts).

6.2.3 Trends for Game Design

Combining the findings from sections 6.2.1.B and 6.2.2.B, we propose the following list of trends stemming from game concepts designed by neurodiverse groups of children. These trends informed our game design process and may serve as a starting point for designing games for groups of neurodiverse children.

A Game of Catch. The classic game of catch was the most prevalent game mechanic in the children's game concepts. Being chased, finding and catching an adversary, though the setting and narratives varied widely, this simple but effective game mechanic reigned supreme.

Elaborate Games. Specifically regarding neurodiverse groups of children, game concepts were rarely simple. To win, a player must complete tasks, testing different skills and stimulating differently.

It Starts at Home. The starting point for the Ozobot in the majority of game concepts was its very own house. The Ozobot's home was the most reoccurring game element, though in most cases, it had no impact on the game beyond being a narrative starting point.

Some Animals are Friends, Others are Foes. Land and marine animals were prominent characters in the children's concepts. Some (for example, whales, birds or rabbits) functioned as aids, while others (for example, spiders, sharks or jellyfish) were obstacles.

Hearts are Lives. Though the game concepts were tangible by design, many children pulled inspiration from their favourite video games. For example, players earn money to buy skins or move freely on an open-world map. However, the most prominent example that made it to several final prototypes was using heart tokens to represent the players' lives.

All Safe Aboard. In several prototypes depicting an aquatic environment, boats were used as safe spaces. When a player's mark was inside a boat, it could not be harmed by, for instance, a shark.

Sports Metaphors. Sports, particularly football, were one of the main interests of the children who participated in this project. Therefore, they made an appearance in their game concepts. For instance, several groups turned the recycling theme into finger football or basketball.

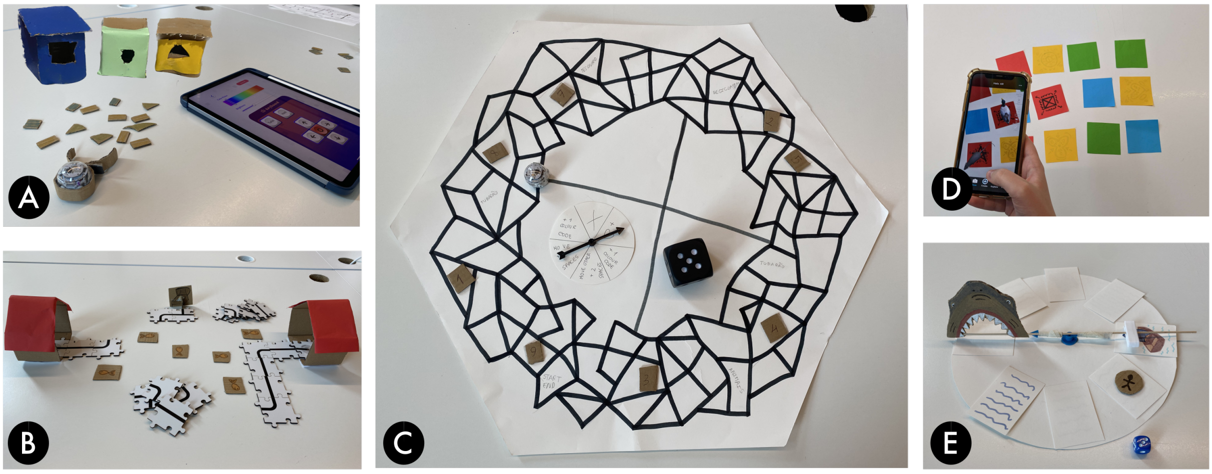

Figure 6.6: Low-Fidelity Prototype. (A) Sorting Trash in Recycling Bins mini-game. (B) Finding an Underwater Treasure mini-game. (C) Gameboard, lucky prize wheel and dice. (D) Rescuing Animals mini-game. (E) Escaping from a Shark mini-game.

6.2.4 Low-Fidelity Prototype

We created a low-fidelity prototype considering the trends identified in section 6.2.3. The central game mechanic and reward system were identical to the game's final version, described in section 6.1. This prototype utilised the same gameboard prototype as the CD sessions, a large physical dice (Figure 6.6.C.), and included four mini-games:

1. Escaping from a Shark - Inspired by the general use of the pinwheel for luck-based dynamics and the trend of boats being safe spaces. This mini-game had a player move a piece between six cards while another rotated a pinwheel decorated as a shark (Figure 6.6.E.). The player would win or lose when the shark landed on the piece based on the current card's content, a boat or water. This mini-game explored single-player dynamics, luck-based games and the absence of technology.

2. Sorting Trash in Recycling Bins - Inspired by the trend of recycling games incorporating sports metaphors. We combine G07's use of the Ozobot to sort trash and G03 and G13's idea of throwing trash pieces into recycling bins into a two-player cooperative game. One player would remote-control an Ozobot with a shovel attachment to sort, and then the other would attempt to score goals with the sorted pieces (Figure 6.6.A.). This mini-game explored cooperative pair dynamics, fine motor skills and the Ozobot.

3. Finding an Underwater Treasure - Inspired by the children's liking of the puzzle activity from session 3 (Section 5.7) and the trend of marine animals as obstacles. We formulated this mini-game with two teams of players, each aiming to guide an Ozobot from a start piece to the treasure. Before building their path with the puzzle pieces, each team placed fish figures in the other's space, limiting their piece placement options (Figure 6.6.B.). The team with the most efficient path won.

This mini-game explored competitive team dynamics, problem-solving skills, the Ozobot and its puzzle.

4. Rescuing Animals - Inspired by G09's use of cards and the classic memory game. This mini-game utilises AR and its potential to enhance the tangible game. Unlike the classic game, all the cards are visually different, with the pairs being revealed through AR, as each card was associated with a 3D model of an animal using the Halo AR app [63] (Figure 6.6.D.). This mini-game explored competitive multiplayer dynamics and AR.

6.2.5 Game-Design Workshop

To test our low-fidelity prototype, described in section 6.2.4, we recruited a group of game-design master's students from Técnico's game-related student groups: Laboratório de Jogos (Games' Lab)[1] and GameDev[2]. Seven students participated in the workshop, one of which had ADHD. After a short introduction to the project, participants play-tested the low-fidelity prototype and voiced their thoughts out loud while a researcher took notes, which two researchers collectively analysed.

6.2.5.A Findings

Participants considered the game engaging but with potential for improvement at this early stage. The Ozobot was the session's highlight, precisely the option to remote-control it. Mini-games took most gameplay time, making the main game mechanic irrelevant. Furthermore, players who were not participating in a particular mini-game grew bored. Participants also pointed out balancing issues in the Rescuing Animals mini-game. Each of these pain points received several improvement suggestions.

6.2.6 Informal Testing Sessions

Over the following month, we continued the iterative refinement process with insights from the game design workshop, described in section 6.2.5. Two to three players from the research team and external to the project tested intermediary prototypes and provided feedback.

6.2.6.A Findings and Refinements

Due to everlasting timing issues in the mini-games, the main gameplay was still not focal, which led to removing the shark-themed mini-game, which became the overall game's theme. As the gameboard was quite complex, the Ozobot rarely got close to the player's pawns, and the players often skipped spaces. This insight led to the simplification of the gameboard. Furthermore, to increase the engagement of

[1] https://labjogos.tecnico.ulisboa.pt/en
[2] https://gamedev.tecnico.ulisboa.pt

the main game, we increased the robot's speed. Other refinements included adjusting the timing on timed mini-games, creating aesthetically appealing versions of game pieces and improving the Ozobot's movement function.

6.2.7 Pilot Test with ND Adults

With a near-ready prototype, we contacted CECD to conduct a pilot test with ND adults. This play-test served to refine the procedure for the game evaluation, described in chapter 7, and showcase the final product of our design process to those who had supported its early stages. Two researchers conducted a small-scale pilot test at the local training centre for adults with intellectual disabilities, with seven neurodivergent students and their teacher, to test run the gameplay experience.

6.2.7.A Findings and Refinements

The participants were enthusiastic about the game. Seeing the robot move around the gameboard and getting to control it in the Treasure mini-game were highlights of the session. The students cheered for each other's wins and laughed off losses. They asked about the game's design process and how we crafted the pieces. This test led to minor adjustments, relating mainly to the physical prototype and the offline setup of the HaloAR app [63], culminating in the final high-fidelity prototype, described in section 6.1.

7

Game Evaluation

Contents

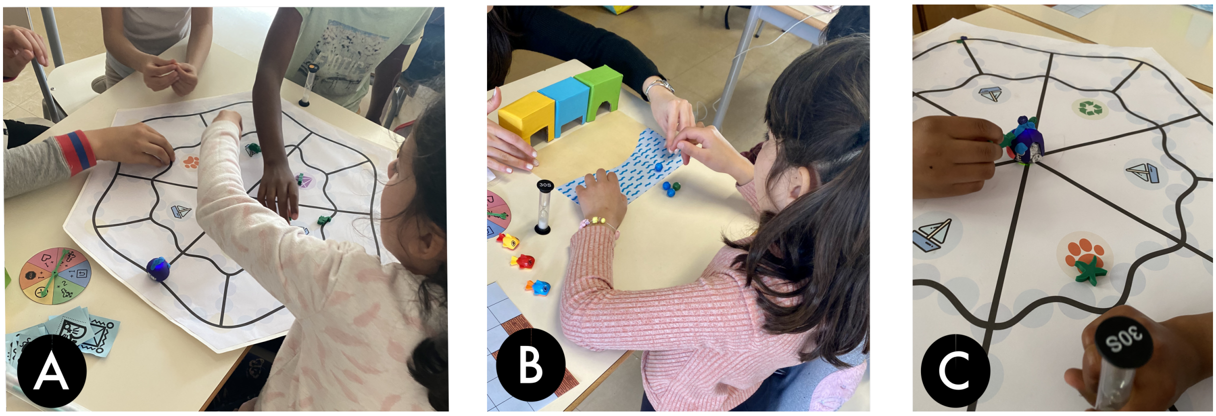

Figure 7.1: Play-test in neurodiverse classrooms. (A) Moving pawns. (B) Recycle mini-game. (C) Reshaping rules.

Finally, we returned to the neurodiverse classrooms with the high-fidelity game prototype, described in section section 6.1, to answer the third research question: **How does the resulting game support inclusive play?**

7.1 Setting and Participants

Similar to the CD sessions, described in chapter 5, we held the play-test at Escola Básica das Lopas. We invited the same four classrooms from the CD process and a fifth control class to play-test the robotic game. The fifth class was a fourth-grade class whose teacher had been present at the initial focus group. Class 5 (9 girls and 10 boys, ages 9-10 M=9.53 SD=0.51) includes groups G17 through G19 and seven ND students: one with Oppositional Defiant Disorder (ODD), three with ADHD and one with both, one with ID and another with speech difficulties. One hundred children (26 ND) tested the game in groups of 4 to 6, with one researcher accompanying each group. We maintained the existing groups for the classes that participated in the CD process.

7.2 Procedure

We began the play-test with a short introduction in line with the CD sessions. A researcher greeted the class and provided an overview of the game's rules and this session's organisation. Afterwards, the researcher at each table further explained the main rules, presenting the game pieces. As players landed on the mini-game spaces, the researcher explained the rules for the given mini-game, reducing the reliance on recall of an initial explanation.

Players sat around a single table with the gameboard in the middle (Figure 7.1.A.). Each researcher set up all the necessary game pieces on an adjacent table. The researcher facilitated gameplay, starting and stopping the Ozobot's movement through the Ozoblockly code, setting up the environment for each mini-game (Figure 7.1.B.) when it came time to play it and reading the dice rolls out loud.

Due to the limited time for this playtest, we cut off the play-testing portion after an hour. Diverging from the proper game rules, we attributed the victory to the player at each table with the most mini-game tokens. As with the mini-games, we encouraged children to determine who won according to the established rules independently. The facilitating researcher remains impartial to such decisions.

Afterwards, we asked children to fill out a questionnaire containing the System Usability Scale (SUS) adapted for children [65], four questions adapted from the Game User Experience Satisfaction Scale (GUESS-18) questionnaire [66], which related to narrative, personal gratification, social connectivity, and visual aesthetics, and two additional questions regarding the child's favourite mini-game and the winner of the game. All questions had the same 5-point visual Likert scale [65].

Finally, we asked some general questions to the class, asking children to raise their hands to answer. In the classrooms that participated in the CD process, we distributed brochures of the game and returned the children's prototypes.

7.3 Data Collection and Analysis

The researchers conducting the final testing sessions created a report of their observations for each group. A researcher then analysed these notes using an inductive coding approach alongside the session's recordings and registered overarching themes, which a second researcher reviewed.

We calculated the SUS score and a score for the three Enjoyment questions for each questionnaire, multiplying the totals to normalise them into 0 to 100 scale. We compared these scores and those of the GUESS-18 questions (0 to 4 scale) between ND and NT children and between the control class (CT) and the remaining ones (CD).

7.3.1 Observations

Children were immediately captivated by the game, pointing at and touching the various pieces. All children could play and grasp the rules. Even taking it upon themselves to run various aspects of the game, such as controlling the time (Figure 7.1.C.), setting up mini-games, or determining if a player has won. The gameplay seemed to equalise groups, balancing out dominant personalities, disruptive behaviour, and typically excluded children. Though the game mechanic was competitive, children often helped each other, sharing tips and prizes. Though some manifested initial frustration at losing mini-games, all seemed happy regardless of the final score, even proclaiming, *"We all win!"* (G05ND1).

Child co-designers recognised their work in the final prototype. Even exclaiming, *"That is our game!"* (G16) upon seeing particular aspects inspired by their concepts. This sense of ownership brought great joy to the students. Children who participated in the co-design process were more engaged in the game throughout the playtesting than in any other activity, focusing solely on the game for the length of the playtest. The control class still enjoyed and understood the game but disengaged from it often. Cheating was frequent among the co-design classrooms. Children often reinvented rules to suit their wishes without protest from their peers. For example, when one child landed on a mini-game, their groupmates would move their pieces to the same space to play it. Rule reshaping was particularly prominent with ND children. For instance, G05ND4 was unhappy with the lack of a container to hold his tokens, electing to attach them to the shark's plasticine fin (Figure 7.1.C.). However, the control group was much more attached to the rules, with children getting mad if someone broke them. The robot was highly engaging for all students; they paid close attention to its movements on the gameboard and were the most enthusiastic towards the mini-game that involved it.

7.3.2 Highlights from neurodivergent children

Some neurodivergent children struggled with counting their pawn's moves. However, this did not affect the overall gameplay. Neurodivergent children from the control group responded with frustration and impatience to the game, struggling with losing or waiting their turn. Two even abandoned the game halfway. Contrastingly, neurodivergent children from the co-design process were fully integrated and included in gameplay, happily playing with their peers.

7.3.3 Questionnaire Responses

We did not encounter any statistically significant results in our analysis. The **System Usability Scale (SUS)** scores were moderately good, with no statistically significant difference between the NT (M=71.56, SD=15.42) and the ND children (M=64.5, SD=14.55), t-test p = .116, or the CT (M=75.42, SD=11.61) and the CD groups (M=70.07, SD=15.41), t-test p = .086. **Enjoyment** ratings were high, with no statistically significant results between in NT (M=85.30 SD=20.15) and ND children (M=83.89 SD=21.24; Mann-Whitney U test$p$ = .935), or the CT (M=89.81 SD=13.87) and CD groups (M=85.00 SD=20.24), Mann-Whitney U test p = .563. The **Game User Experience Satisfaction Scale (GUESS-18)** questions regarding Narrative, Visual Aesthetics, Personal Gratification or Social Connectivity showed overall positive opinions but no statistically relevant differences among groupings (Mann-Whitney U tests, all p 0.05). The children's **favourite mini-game** was Treasure, which allowed children to control the robot (35 of 71 answers). The remaining two mini-games tied in popularity (15 out of 71 answers each). Six children reported liking all the games equally.

The lack of statistically significant results between the ND and NT children indicates that their gameplay experience was enjoyable and similar, as evidenced by the observational insights. However, the mean SUS score from ND children was 64.5, indicating below-average usability, possibly due to their struggle with counting spaces on the gameboard.

Regarding the control class, the lack of significant quantitative results indicates that the children perceived the game similarly to their schoolmates participating in the co-design sessions. However, their behaviours during gameplay contrast regarding rule adherence and engagement, indicating that ownership and co-design bias affected gameplay.

7.4 Discussion

Overall the game achieved its goal of creating an inclusive and engaging playing experience for neurodiverse groups. Reflecting upon the findings presented above and our game design process, described in section 6.2, we propose the following recommendations for the design of inclusive games for neurodiverse groups of children:

Put fun on the forefront. When designing inclusive play experiences for neurodiverse groups, fun should be the primary goal. Include elements that play to the children's interests and preferences, and do not let "serious" goals hinder the most important one.

Create clear and concise rules. The more children rely on recall during gameplay, the less independently they can play. Complex rules that require consulting a rulebook might not be accessible to neurodivergent children.

Encourage social interaction through a shared environment. The use of tangible elements, a robot, and a centralised gameboard shared by all players contributed to pro-social behaviours through joint attention.

Help children find their place. Gameboard designs should be minimalistic and clearly showcase spaces with unique in-game relevance. Consider finding alternatives or aids to counting spaces, as this mechanic is not accessible to all neurodivergent children.

Give tangible rewards. Physical tokens representing children's in-game accomplishments create excitement and aid in keeping score. Including some randomness in these rewards allows was also very well received.

Diversify your game mechanics. Neurodiverse groups of children showed a preference for diverse games. Including mini-games that rely on different skills and player roles allows games to please all players.

Fight boredom at all costs. Neurodivergent children are more likely to disengage from a task if they find it fatiguing. Using timers to keep gameplay agile and giving all players active roles helps keep neurodiverse children engaged, even when it is not their turn.

Embrace technological options. Technology is highly engaging for both neurodivergent and neurotypical children. Including it in games is an easy choice. However, diversity is vital; while some children might love robots, others prefer AR, and meeting the most preferences will yield a better game.

7.5 Limitations

Though children's evaluations of the game were overall positive, the gaming experience of ND children from the control class was not as engaging as we had envisioned. Their lack of ownership over the game diminished their enjoyment, indicating a strong CD bias. Moreover, the CD group's experience work working together over four months created inclusive dynamics that improved the play experience. This indicates that besides inclusive games, implementing inclusive classroom practices, such as group work, is a key step for the inclusion of ND children in neurodiverse classrooms.

Using questionnaires with children within this age group in a classroom context was not entirely efficient, with some struggling to read and rushing through questions, which might have created inaccuracies in the data. Furthermore, the research team translated the questionnaires to the local language and adapted the questions from the GUESS-18 questionnaire [66] to a more child-friendly speech; these adaptions still require formal validation.

8

Conclusion

Contents

Play is an essential element of early childhood development. Children develop social, emotional and intellectual skills through play. Most childhood play experiences occur in school, where children spend most of their time. Globally, in recent years, classroom settings have grown to be inclusive of children with different abilities. The push toward inclusive education is beneficial to all students. However, the supports built for it focus on inclusive learning rather than inclusive play. In this dissertation, we take on the lens of neurodiversity, aiming to explore the inclusive potential of co-designing a robotic game with ND and NT children.

Through our formative studies (Chapter 4), a focus group with teachers, and interviews with ND adults, we have identified facilitators and barriers to both inclusive play and inclusive group work with neurodiverse groups of children. With this information, we planned and executed five CD workshops (Chapter 5) with each of the four participating neurodiverse elementary school classrooms. From the analysis of the recordings and observation notes of the CD process, we provide best practices for co-designing robotic games with neurodiverse children. Furthermore, we detail the game design process (Chapter 6), the refinement of children's concepts into a cohesive game. Finally, we present the evaluation of the co-designed game (Chapter 7), presenting design recommendations for robotic games for neurodiverse players.

Our formative studies engaged secondary stakeholders in reflections about the inclusion of ND children in mainstream classrooms. We contribute to ongoing research on inclusive computing and inclusive education with a series of barriers and facilitators for inclusive activities. Our findings reveal that the placement of ND children in mainstream classrooms and the prevalence of groupwork contribute to the social inclusion of ND children through repeated engagement with their NT peers. Technology and teachers are highlighted as key aspects for inclusion However, they can just as easily contribute to exclusion if not handled correctly. Finally, we highlight moments of play as children's measure of inclusion, further cementing our project's motivation.

Throughout the CD workshops, neurodiverse groups of children worked together to create game concepts utilizing robots and tangibles. We build upon previous work in the field of CD by leveraging preexisting methods and adapting them to neurodiverse groups. Moreover, co-designing in a classroom setting had repercussions beyond game design. The process impacted classroom and group dynamics, but it was also moulded by its environment. We reflect on this bilateral impact, re-contextualizing our findings from the formative studies through the lens of our lived experiences co-designing in neurodiverse classrooms. Furthermore, we propose best practices for conducting CD in this setting, such as explicit group dynamics and session deliverables, encouraging resource sharing and physical closeness and promoting and continuity.

Regarding our game design and evaluation process, we provide a methodological background for converting CD findings and outputs into a concrete game over which the co-designers still maintain ownership. Reflecting on the play-test results in neurodiverse classrooms, we provide recommendations for future work in the field of game design for neurodiverse groups. For instance, we suggest game designers put fun in the forefront and leverage tangibles, technology and a joint environment to promote an inclusive gameplay experience.

In the end, we achieved our principal goal of promoting inclusion in neurodiverse classrooms, both through the CD process and the co-designed game. Notably, groups who participated in the CD sessions grew more understanding and tolerant, with both ND and NT children forming strategies for equitable groupwork. The co-designed game proved engaging for all children, and though some ND children did not fully grasp some of its concepts, this did not hinder gameplay.

8.1 Future Work

When conducting our formative studies, we only engaged with secondary stakeholders. Findings, stemming from the educator focus group specifically, did not fully correspond to the realities we found while conducting the CD process in these classrooms. Hence, we intend to build on our existing list of barriers and facilitators for inclusion through a longitudinal observational study, as proposed by Neto et al. [67].

Though our CD process proved effective and inclusive, we learned many lessons throughout its run. In the future, we aim to bring an improved version of this CD methodology to other neurodiverse classrooms. Given the wide spectrum of neurodivergence, a larger sample would allow us to refine this methodology further and validate it while promoting inclusion within more neurodiverse classrooms. Furthermore, socioeconomic settings can play a part in schools' social dynamics. Therefore, extending our findings to diverse school environments would account for these factors.

Our play-test with the control class indicated that CD bias strongly impacted the children's behaviour while play-testing the co-designed game, but not on their perceptions of it. In future studies, we plan to further investigate this aspect by evaluating the game with more control classrooms and with the CD classrooms after a longer interval.

We recognize the impact of conducting a longitudinal research project within a school setting. Children grew attached to the research team and the project through out the four-month process. Our efforts to give children ownership over their creations were fruitful. Nevertheless, more must be done to infrastructure continued impact in the classrooms after the CD project ends. As a first step, we plan on creating robust game prototypes to gift to the schools. Afterwards, we might measure the impact of the game without the presence of researchers as an influencing factor.

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A

IST's Ethics Committe Approval

TÉCNICO LISBOA

Ethis Commission (CE-IST)

Ref. n.º 2/2023 (CE-IST)
Date: 02/02/2023

Name of IR: Prof. Hugo Miguel Aleixo Albuquerque Nicolau

Name of the project: Inclusion through Play: Co-designing Inclusive Robots with Neurodivergent and Neurotypical Children.

Prof. Hugo Miguel Aleixo Albuquerque Nicolau

The Ethics Committee of Instituto Superior Técnico (EC-IST) reviewed your application to obtain ethical assessment for the above mentioned project. The following documents have been reviewed:

Ref.	Documents	Version & date
1349499	Sessões de Co-Design - Consentimento Informado-2.pdf Formulario COMISSAO DE ETICA IST 09-11-2021.pdf Sessões de Teste - Consentimento Informado-2.pdf Grupo Focal Educadores - Consentimento Informado-2.pdf Entrevistas Adultos Neurodivergentes - Consentimento Informado-2.pdf	14/10/2022

The following members of the EC-IST participated in the ethical assessment:

Name	Role in Ethics Committee	Qualification	Gender	Affiliation to IST (Yes/No)
Mário Gaspar da Silva	President	Professor	M	Y
Isabel Trancoso	Member	Professor	F	Y
Isabel Sá Correia	Member	Professor	F	Y
Fernando Borges Araújo	Member	Professor	M	N
Miguel Prazeres	Member	Professor	M	Y

This EC-IST is working accordance to ICH-GCP, Schedule Y and ICMR guidelines, the EC-IST regulation and other applicable regulation.

None of the researchers participating in this study took part in the decision making and voting procedure for this assessment.

Based on the review of the above mentioned documents, the EC-IST states a favourable ethical opinion about the request / trial as submitted.

The EC-IST expects to be informed about the progress of the study, any Serious Adverse Events occurring in the course of the study, any revision in the protocol and in the participants' information/informed consent, and requests to be provided a copy of the final report.

Prof. Mário Gaspar da Silva
President of Ethics Committee of
Instituto Superior Técnico (CE-IST)

B

Children's Demographics

Table B.1: Demographics from Class 1

Group	Pseudonym	Gender	Age	ND	CD Sessions	Notes
1	G01NT1	F	9		All	
	G01NT2	M	12		All	
	G01ND3	M	9	LD	All	
	G01NT4	F	9		All	
	G01NT5	F	10		All	
2	G02ND1	M	9	LD	All	
	G02NT2	F	10		1,2,4,5	
	G02NT3	F	9		1.2	transfered schools
	G02NT4	F	9		All	
	G02NT5	F	10		4.5	transfered schools
	G02ND6	M	11	LD	All	
3	G03NT1	F	9		All	
	G03NT2	M	9		All	
	G03ND3	M	9	LD	All	
	G03ND4	F	10	Dyslexia and LD	All	
	G03NT5	M	10		All	
4	G04NT1	F	9		All	
	G04NT2	F	9		All	
	G04NT3	M	9		All	
	G04NT4	F	9		All	
	G04NT5	F	10		1,2,3,4	

Table B.2: Demographics from Class 2

Group	Pseudonym	Gender	Age	ND	CD Sessions	Notes
5	G05ND1	F	9	ID	All	
	G05NT2	M	9		1,2,4,5	
	G05NT3	M	9		All	
	G05ND4	M	9	ID	2,3,4,5	
6	G06ND1	M	9	LD	1,3,4,5	
	G06ND2	M	9	ADHD	All	
	G06ND3	F	9	ADHD	All	
	G06NT4	F	9		All	
	G06NT5	F	8		2,3,4,5	
7	G07NT1	F	9		All	
	G07NT2	F	9		All	
	G07NT3	F	8		All	not fluent in local language
	G07NT4	F	10		All	
8	G08NT1	F	9		All	
	G08NT2	F	9		All	
	G08NT3	F	9		All	
	G08NT4	M	9		1,2,4	

Table B.3: Demographics from Class 3

Group	Pseudonym	Gender	Age	ND	CD Sessions	Notes
9	G09NT1	F	7		All	
	G09NT2	F	7		1,3,4,5	
	G09NT3	M	7		All	
	G09NT4	M	7		1,3,4,5	
	G09NT5	F	7		2,3,4,5	
10	G10NT1	M	7		1,3,5	
	G10NT2	F	7		All	
	G10NT3	M	8		All	
	G10NT4	F	7		All	
	G10ND5	M	7	LD	1,3,4,5	
11	G11NT1	M	7		All	
	G11NT2	M	7		All	
	G11ND3	F	6	LD	All	
	G11NT4	M	8		All	not fluent in local language
	G11ND5	M	8	Trisomy 21	1	
12	G12ND1	F	6	LD	All	
	G12NT2	M	8		1,4,5	
	G12ND3	M	7	LD	All	
	G12NT4	M	7		All	
	G12NT5	F	7		All	
	G12C6	M	6		1,3,4,5	

Table B.4: Demographics from Class 4

Group	Pseudonym	Gender	Age	ND	CD Sessions
13	G13ND1	F	8	GDD	All
	G13NT2	M	7		1,2,3,4
	G13NT3	M	7		All
	G13NT4	M	7		All
	G13NT5	F	7		All
14	G14NT1	F	8		All
	G14NT2	F	7		All
	G14NT3	M	7		All
	G14NT4	F	8		All
	G14NT5	F	7		2,3,4,5
15	G15NT1	M	7		All
	G15ND2	M	7	LD	1,2,3,4
	G15NT3	F	7		All
	G15NT4	M	7		All
	G15NT5	F	7		All
	G15NT6	F	11		All
16	G16ND1	M	9	LD	All
	G16NT2	M	9		All
	G16NT3	M	8		1,2,3,5
	G16NT4	M	7		All
	G16NT5	F	7		All
	G16ND6	F	7	LD	All

Table B.5: Demographics from Class 5 (Control Class)

Group	Pseudonym	Gender	Age	ND	Notes
17	G17NT1	M	10		
	G17NT2	F	9		
	G17ND3	M	10	ODD	
	G17NT4	F	9		
	G17NT5	M	9		
	G17ND6	M	10	ADHD	
18	G18NT1	F	9		
	G18NT2	M	10		
	G18ND3	M	10	ID	
	G18NT4	F	9		
	G18NT5	M	10		
19	G19ND1	F	10	ADHD	
	G19NT2	F	9		arrived at the end of session
	G19ND3	F	9	ADHD/ ODD	
	G19NT4	F	10		arrived at the end of session
	G19NT5	F	10		
	G19NT6	M	9		
	G19ND7	M	10	Speech Difficulties	
	G19ND8	M	9	ADHD	