MSc Human-Computer Interaction and Design
Final Project

Nudgo: An interactive system for neurodiverse social connections

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Contents

Abstract

This thesis presents the design and testing of a system called the Nudgo system to support the connection-building between autistic children and neurotypical adults. The exploration of this project began with a general interest in how humans build social connections and make sense of them. First, the embodied and enactive cognition theory [14] highlights that our bodies play a fundamental role in shaping our cognitive abilities. Furthermore, the concept of participatory sense-making [23] expands on the idea of enactive cognition by incorporating the social domain. Through interactions, we actively participate in each other's sense-making by collectively generating and transforming meaning. These theories lay the foundation for analyzing and modelling interpersonal connections in this project. According to participatory sense-making, social understanding is no longer solely the responsibility of the individual. This is also applied to social interactions between autistic people and non-autistic. For autistic children, it is always difficult to establish social connections due to challenges in reciprocal social interaction skills [33]. Fortunately, the introduction of the double empathy problem [55] has changed how we view the interaction between autistic and non-autistic individuals and provides new opportunities for their social connections. It highlights the importance of offering support during the interactive process rather than just focusing on correcting autistic children's behaviour. Our objective in this research is to create a system that can provide assistance for interactions between autistic children and neurotypical adults, making it easier for them to establish rapport and intimacy. To enhance the research and design process of this project, I employ the Research through Design (RtD) methods [98]. The system undergoes iterative design and refinement across multiple cycles. The whole process is divided into five activities: ideation, design, implementation, workshop, and theory development. Additionally, A combination of User-centered Design (UCD) [48] and Co-design [69] approaches is adopted in workshop activities to better engage target users in the design process. The main outcomes of the research are early prototypes of the Nudgo system, one in wall form and one in tunnel form. These prototypes, combined with workshop observations, provide invaluable insights and future guidelines for the design of the final product. Moreover, the design concept and validation have effectively addressed the majority of the key research questions presented in the thesis. The strategies outlined in this research can readily be applied to other RtD projects with similar interests. In the discussion section, sincere suggestions were also proposed for projects advanced using the RtD method in this study.

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Chapter 1

Introduction

1.1 Interaction and Connection

At the end of the day, why do we need to interact with others? If possible, can we just stay alone and detach ourselves from society? And what do we hope to gain from these interactions?

In the movie "Into the Wild," Christopher McCandless leaves society behind and begins living in a forest in Las Vegas. After finding the truth he was seeking, he tries to return from his wilderness adventure in spring. However, the stream that he crossed last winter has become too wide and turbulent. Unable to cross the river to return to society and fall sick alone, he writes in his notebook before his death: "Happiness is only real when shared."

Social connections are a fundamental aspect of human interaction and are integral to our emotional, psychological, and physical well-being. Regarding why human beings need social connection, Fromm said:

> "Man—of all ages and cultures—is confronted with the solution of one and the same question: the question of how to overcome separateness, how to achieve union, how to transcend one's own individual life and find atonement."[34]

Pursuing the connection between individuals is a way to overcome our sense of separateness and break free from the confinement of aloneness. Separateness means a state of disconnection from the outside world and an inability to exert one's power. A feeling of separateness is the root cause of intense anxiety [34]. And sometimes, the same anxiety keeps us from building connections proactively. When we feel separate, it goes beyond helplessness. It's also a struggle or inability to understand and connect with the world, other people, and things. This can leave us feeling overwhelmed and out of control.

1.1.1 Rapport and Intimacy

Human connections are intricate and mysterious. There are numerous ways to describe them, but no one sentence can show it all. They cannot be proven like mathematical formulas or touched like trees. However, although there are significant individual differences, we are still seeking some common elements in an attempt to piece together this magnificent tapestry. Perhaps, as Carl Jung said, it is a certain need or archetype hidden within our collective unconsciousness. Some research has tried to help us uncover this mysterious veil from notions like rapport and intimacy.

Rapport can be understood as positive and smooth interactions characterised by harmony and agreement [49, 91]. It is considered both a goal and an essential aspect of quality in both one-time and repeated conversations or meetings. The conceptualisation of rapport is complex. Sometimes, people describe such wonderful experiences as feeling "in sync" or "clicking" with the interaction partner. They experience rapport when a combination of qualities emerges from each person during an interaction. Tickle-Degnen and Rosenthal attempted to form the complicated rapport structure from three essential components: mutual attentiveness, positivity and coordination [82].

In Tickle-Degnen and Rosenthal's study on long-term interaction tracking, participants with a high degree of rapport usually become unified and cohesive through mutual attention and involvement[82]. Their attention is no longer inward but towards the other. Such intense mutual interest and focus, which is called *mutual attentiveness*, is the foundation of rapport. Moreover, a high level of mutual attentiveness can have both positive and negative implications. However, a sense of rapport can only be established when there is mutual friendliness and genuine concern, where *positivity* is essential. Finally, even though a high degree of mutual attention and positivity can bring positive valence, there is something more to rapport - such as fewer misunderstandings in communication and more immediate, spontaneous, and sympathetical reactions. In interpersonal interaction, such kind of synchronisation or smooth action is referred as *coordination*, which leads to less awkwardness. It is related to the feeling of balance and harmony.

On the other hand, *intimacy* results from an interaction where one person shares personal information with their partner and receives responsive communication in return. It has been extensively studied for its positive impact on relationship satisfaction and perceived social support [64, 60, 41]. Laurenceau et.al proposed that intimacy consists of two key elements: self-disclosure and partner responsiveness [52]. Intimate interaction is not just about one-directional sharing, but rather a dynamic and reciprocal process between individuals. It is only when the discloser subjectively feels their partner's responsiveness that they can truly experience intimacy in the interaction.

Intimacy and rapport are both formed and developed over time, based on mutual sharing and understanding. This dynamic temporal aspect of intimacy and rapport development is neglectable. It affects the judgment and actions taken by social participants towards each other at different stages. The patterns of interaction between strangers who have never met before and those who have had a few interactions are different. In the field of interpersonal relationship development, scholars have proposed that initial encounters are influenced by culturally acceptable and stereotypical behaviour [9, 25]. Due to participants' unfamiliarity with each other, there is often a degree of awkwardness and miscommunication. Later, as participants become more familiar with each other, interactions become more loosely structured, and they develop their own communication conventions. For example, the structure of rapport always includes mutual attentiveness, positivity, and coordination. However, the relative importance of these components within the structure varies as a relationship between individuals develops. In intimate relationships, individuals can more easily share personal thoughts, feelings, and experiences. Rapport supports this sharing by creating a non-judgmental and accepting atmosphere, especially in forms of non-verbal cues.

In conclusion, intimacy and rapport can serve as important indicators of the qualities of social connection. From an emotional demands standpoint, nothing satisfies a person more than genuine intimacy and rapport in social connections. However, it is worth noting that the important elements introduced here are only a part of the patterns presented. We must acknowledge that all connections are context-based and socially situated.

1.1.2 Autism and Neurodiversity

Autistic individuals, often overlooked by society, have a significant need for social connections. It is crucial for their well-being and overall quality of life. However, their connection needs are usually misunderstood or difficult to understand. Before delving further into this topic, let's first introduce the group systematically.

Autism is a spectrum condition that manifests with diverse symptoms, which can differ greatly among individuals diagnosed with it. Along with other disorders such as Asperger's syndrome and pervasive developmental disorder not otherwise specified (PDD-NOS), it falls under the umbrella term of Autism Spectrum Disorder (ASD) [33]. According to the conventional understanding and diagnostic definition, Autism Spectrum Disorder is a cluster of neurodevelopmental disorders [78] characterised by persistent deficiencies in social communication and interaction across multiple contexts, as well as by restricted, repetitive patterns of behaviour, interests, or activities, and hyper- or hypo-reactivity to sensory input or unusual fascination with sensory aspects of the environment [10].

As the term *spectrum* encompasses a wide range of conditions collectively known as autism, what unites all these symptoms is an inherent challenge in engaging in typical social interactions. Furthermore, there is a consistent rigidity in behaviour that leads to various consequences. Frith summarized in his book three core features of the autism spectrum as follows [33]:

- Reciprocal social interaction: challenges in establishing and maintaining relationships, understanding others' emotions and intentions, and experiencing emotional resonance.

- Communication difficulties: challenges in both verbal and nonverbal communication. These can include delayed language development, difficulty comprehending language, limited language expression, and a lack of synchronization between facial expressions and body language.

- Restricted and repetitive behaviour: display of repetitive and stereotyped patterns of behaviour and interests, which includes actions being repeated, excessive fixation on specific things or topics, and having narrow and rigid interests. These behaviours and interests are often excessive, narrow, and inflexible.

Research indicates that there has been a global increase in both the raw prevalence and disability associated with ASD over the past three decades (1990-2019) [75]. In 2019, more than 28 million people worldwide were affected by ASD [89]. It is also estimated that all over the world, about 1 in 100 children have autism [96]. Such an increase is not mysterious nor indicative of an epidemic. Nowadays, both children and adults are being diagnosed with autism who may not have received a diagnosis in the past [75]. In previous times, many of these individuals would have been categorised as mentally disabled. This rise is closely linked to expanded diagnostic criteria, heightened awareness, and improved identification and services for affected children [53].

With the expansion of this community comes the autism rights movement, also known as the autistic acceptance movement, which has become increasingly active since the 2000s [6]. The movement advocates for greater acceptance of autistic traits and behaviours. It proposed reforms in services that focus on improving quality of life instead of suppressing or masking adaptive traits. Furthermore, they also create social networks and events where autistic individuals can socialise on their own terms [57, 6].

During the movement, the neurodiversity paradigm was reintroduced and further promoted. *Neurodiversity* is a proposed notion that recognises the inherent diversity in human brain function and cognition. It was first introduced by Judy Singer in 1998 to acknowledge that each person's brain develops in a distinct manner [17]. The neurodiversity paradigm suggests that certain conditions currently labeled as neurodevelopmental disorders should be viewed as differences and disabilities rather than inherently pathological. For instance, it views autism as a variation in the human brain rather than a disease to be cured.

Neurodivergent[1], which originated from the concept of neurodiversity, refers to individuals whose brain differences affect their cognitive abilities, resulting in unique strengths and challenges [17]. They exhibit non-dominant cognitive styles which manifest as differences in sensory processing and social interaction. In contrast, those with dominant cognitive styles are referred to as *Neurotypical*.

1.1.3 Double Empathy Problem

Peer relationships and friendships play a crucial role in the social and cognitive development of autistic children [66]. They not only enhance their academic performance but also contribute to fostering a positive school environment. Such connections can help children with autism decrease victimisation and refine their prosocial behaviours. However, the quality of their friendships was generally poorer in terms of companionship, security, and help [66, 13]. Due to unique perceptions, experiences, and interactions with their surroundings, as well as the inability to verbally communicate these experiences to the majority of the population, autistic individuals may experience poor social support and increased loneliness compared to their neurotypical peers [15, 35].

Despite common misconceptions, individuals with autism are not anti-social [20]. If we look carefully and deeply, social interaction in mixed neurotype groups (e.g. autistic and non-autistic) is frequently perceived as immensely challenging by all participants, not only the autistic person. Milton coined the term *Double Empathy Problem* to describe such difficulties that arise when neurotypical individuals and those with autism try to understand each other. It is a mismatch in the interaction between an autistic and non-autistic pair, where both individuals encounter a breach in their "natural attitude" while trying to communicate [56]. Just like two people from different cultural backgrounds who do not understand each other's culture trying to communicate, they will find it extremely difficult. Furthermore, misunderstandings between each other will further deepen the estrangement. Partly due to differing social interaction expectations [55], feeling misunderstood can lead to awkwardness and a perception of reduced trustworthiness or likability in one-on-one interactions between autistic and neurotypical individuals [8, 28].

There are two research strands that offer empirical support for the Double Empathy Problem. One area of research has focused on the challenges that non-autistic individuals face when interacting with autistic people. For example, non-autistic individuals struggle to accurately interpret facial expressions and understand the mental states of autistic individuals [26]. What's more, non-autistic people usually overestimate how egocentric autistic family members are, while also overestimating the helpfulness of their own behaviours toward autistic people [39]. The other research area focus is to examine inter-autistic communication and interaction. For instance, there are distinct characteristics in the way autistic individuals interact with one another. They often express that their interactions

[1]It is worth noting that neurodivergent is not a medical term, condition, or diagnosis. It refers to individuals who have differences in the functioning of their brains. This remains true even among people with the same medical diagnosis, indicating that individuals with distinct signs and symptoms can still share a common diagnosis. ASD is one of the conditions that are most common among those who describe themselves as neurodivergent, other conditions include attention-deficit hyperactivity disorder (ADHD), dyslexia (difficulty with reading), and sensory processing disorders, etc.

with fellow autistic individuals are more comfortable and easier compared to interactions with nonautistic individuals [20]. It seems autistic people are less likely to find non-typical social behaviours in other autistic people problematic [74].

In particular, this study focuses on the interaction between children with autism (6 to 10 years) and neurotypical adults. In this case, due to the differences in individual developmental stages (influenced by age and social experience), the disparities between both parties will be more pronounced. For instance, Jean Piaget's 4-Stage Cognitive Model is a significant theory in developmental psychology that illuminates the growth and learning process of children [88]. The cognitive development of neurotypical children can be summarized into four stages: sensorimotor stage (birth to 2 years), preoperational stage (2 to 7 years), concrete operational stage (7 to 11 years), and formal operational stage (12 years and older). When children start school education at the age of 5 to 7, they are in the preoperational stage. During this period, children develop abstract thinking skills such as counting on their fingers, questioning the reasons behind things, refusing tasks unless they understand their purpose, and more. They also enhance their language abilities, comprehend symbolic concepts, and invent their own games. However, they often exhibit egocentric behaviour and find it challenging to consider others' perspectives [51]. Moving on to the concrete operational stage, children become significantly more skilled in logical reasoning. The egocentrism observed in the previous stage starts fading away as kids improve their ability to contemplate how others might perceive a given situation.

However, it is crucial to recognise that the chronological age of some children may not correspond to their maturation age, especially among autistic children. Cognitive development is now understood to be more fluid than Piaget's model suggests, with children often developing skills at different rates [51]. Autistic children can have significantly different developmental situations. So, although we may expect an older child to get along with others, share equipment, get on with work tasks, etc, they may not be developmentally equipped. This means that the issue of double empathy will be even more prominent in this situation. When working with autistic children in particular, it is important to acknowledge that they perceive the world in which they live very differently compared to non-autistic, adult participants and researchers.

Despite the extensive discussion on new perspectives towards Autism, we cannot deny the role of traditional interventions and various therapies. Without these foundational treatments and experiences, it would be difficult for neurodivergent individuals to express their needs in a communicable manner, and neurotypical scholars would never fully understand the importance of these demands. However, solely focusing on survival issues is insufficient to address potential future challenges. Approaching this issue in a more dignified manner not only shows respect for the neurodivergent community but also reflects a fundamental reflection on human needs and an in-depth process of humanistic care. The benefits brought about by this approach will extend beyond just assisting individuals with Autism.

1.2 Research Questions

Whether we like it or not, the fact is most of our minds, especially those who are young and living in cities, are shaped by technology. Even if we now move to somewhere without modern civilisation, how we think and behave has already been shaped. Not to mention that it has long been indispensable in our lives. It is not only a matter of mobile phones or laptops, but all home appliances, public systems, and transportation. Technology has the power that makes us unable to live without it even though, in some situations, we do not like it from the bottom of our hearts.

Among modern technologies, many of them are for social interactions - from social media platforms to instant messaging apps and video conferencing tools. The success of these communication products proves that technology is a powerful tool for supporting social interactions. However, Norman argues that what people perceive as means of social connections or emotional bonds actually emerged as a byproduct of deployment [59]. They were designed originally merely for communications, but not intended for building trust or bonds.

For autistic individuals and their families and friends, this situation is unfavourable. Technology, as a tool, can both facilitate communication and amplify misunderstandings. Without a powerful inclusive system to provide bridges, technology will only become an obstacle in establishing connections between autistic and neurotypical individuals. Therefore, I am trying to find a way to address the double empathy problem in our more technologically advanced society, at least partly. Twenty years after Judy Singer proposed it, neurodiversity was suggested as a specific topic within the framework of Diversity Computing (DivComp) [29]. This framework encouraged individuals to reflect on their biases, question their assumed objectivity, and challenge any negative impacts. In DivComp, they described a future design as follows:

> A DivComp device would provide realtime feedback for the non-autistic conversation partner about the level of arousal or anxiety, and the regulatory effects of stimming behaviors[2]. Equally, the autistic person would receive feedback on how confusing or uncomfortable their behaviors are for their conversational peer. Both parties could use this information to regulate aspects of their interaction, reflecting on individual needs (e.g., coming to rest, feeling comfortable) and building a shared meaning as conversational partners [29].

Such vision provides direction for the positioning of this research. This project strives to find a supplement to modern screen-based interaction design and try to help mediate the tense and easily misunderstood parts of interpersonal relationships in a gentle way. To pursue this very abstract human connection topic, embodied and enactive theory provides a balanced perspective for explaining relationships between people. It expanded from our body and cognition relationship to our relationship with the world and other people. And theory alone is not enough. The way to solve specific complex and concrete design issues will become the main focus of this article. Therefore, the main research question of this thesis is:

> **How can we design an interactive system aimed at building neurodiverse social connections in support of embodied and enactive cognition?**

In order to answer this question, we must first address the following sub-questions, as they collectively form the main aspects of this inquiry:

> 1) How does the embodied and enactive cognition theory inform the system design and the act of designing?

[2]Self-stimulatory behaviors, also referred to as "stimming," are repetitive and stereotypical movements of body parts or objects [63]. Some behaviours are considered as stimming, such as assembling the same puzzle repeatedly, stroking,or touching the body.

2) What are the design strategies we can use to design this system for neurodiverse social connections?

3) What is the essential support of the design process for such a special system?

4) How can we determine the success of this design project?

In the first half of the introduction, I explained why we design interactive systems aimed at building social connections for individuals with different neurotypes. Next, we need to understand how to use the embodied and enactive theory to support our design in order to move away from the old mindset of prioritising efficiency and creating new possibilities, which are covered in Chapter 2. Further, representative system designs for neurodiverse social connections are selected in Chapter 3. As systems specifically designed for neurodiverse social connections are rare, I also include many cases of general social connection and analyse the strategies they use.

The process of user interaction with a well-designed system is a small but noticeable part of the design process. It is like the tip of an iceberg floating above the sea level. As an inexperienced designer starting from scratch, I also pay extra attention to how to build an ecosystem to support design. This support includes the cultivation of design thinking, the selection of design methods, the application of tools and technology, as well as the integration of design and research. For instance, to store the information and insights of design in the scientific literature system, this work applies the Research through Design (RtD) methodology [32]. A combination of User-centered Design (UCD) [48] and Co-design [69] approaches is used to address the interactions among users, products, and design researchers. These methods will be introduced in detail in Chapter 4.

Because of the application of RtD, UCD and Co-design methods, the design exploration involves activities such as design, implementation, and workshops. These concrete design attempts and activities are introduced in Chapter 5, Chapter 6, and Chapter 7. Among them, Chapter 5 focuses on the introduction of neurodiverse interactive contexts, while Chapter 6 and Chapter 7 are specific practices. Finally, in Chapter 8, I summarized the strategies in design practice and further proposed future design plans. In Chapter 9, the evaluation and reflection on the entire project are explored.

Chapter 2

Theories

2.1 Embodied and Enactive Cognition

Typically, we consider the brain as responsible for cognition. However, it is important to recognize that the brain is part of a body - a body that moves and interacts with the environment. This raises the question: what role does the body play in cognition? Some philosophers argue that it has no significant impact on how we think [72]. On the other hand, others believe that the body is essential to cognition because it is closely involved in cognitive processes such as acting and perceiving [54, 95]. The theories of embodied and enactive cognition highlight the importance of the body in understanding cognition.

2.1.1 Embodiment and Embodied Sense-making

The term *embodiment* refers to how an individual's own body influences their experiences and cognitive abilities within their specific context, suggesting that our bodies play a fundamental role in shaping these aspects of our lives [14]. *Cognition*, also known as *sense-making*, refers to how individuals constantly interact with the world and how certain aspects of their experiences become meaningful during that dealing or interaction [87]. It is like a funnel that narrows down the complexity of the world.

Sense-making and embodiment are closely intertwined. The enactive approach views sense-making as embodied action, as our bodies play a significant role in shaping our interactions with the world. Thus, the process of generating meaning is called "enaction" instead of "representation", and making sense is related to "knowing-how", which should be distinguished from "knowing-that" [68]. *Knowledge*, from facts and ideas to most abstract forms, is ultimately based on "knowing-how", our practical embodied skills and abilities. For example, simply knowing the name of a plant without actually seeing it, smelling it, touching it, or even cultivating it is not enough for complete understanding.

Embodied sense-making is characterised both by ongoing loops of sensing and acting, which we call 'sensorimotor coupling', and by the ever-present social context, which we call 'social situatedness' [87]. *Sensorimotor coupling* refers to the simultaneous interaction between action and perception. It involves the continuous flow of sensorimotor activity, which leads to temporary connections between what we see and what we do [87]. In contrast to a sequential model where perception solely determines our behaviours, this concept recognises that our actions also influence our perceptions. Furthermore, sensorimotor couplings are influenced by social interactions and norms, which is not a pure interaction between ourselves and the physical world [67]. Individuals are always *socially situated*. No matter whether others are physically present, our cognitive activity is defined, interpreted, and supported by others. Even an empty cup on the table can immediately indicate someone was drinking tea there before. Physical objects in human activities are usually perceived as social objects.

2.1.2 Participatory Sense-making

De Jaegher proposed *participatory sense-making* as a way to integrate the social and sensorimotor aspects of sense-making [23]. They extended the enactive concept of sense-making into the social domain. Through interactions, we actively participate in each other's sense-making by collectively generating and transforming meaning. The notion of participatory sense-making defined a spectrum of participation, from simpler cases of orientation of individual sense-making to joint sense-making where individuals fully and directly participate in a joint process of sense-making. In this theory, social understanding is no longer solely the responsibility of the individual. Even in cases where sense-making is primarily an individual activity, it is still influenced by coordination during interaction.

In participatory sense-making theory, the *interaction* process can take on a form of *autonomy*. For instance, in a social encounter, our interactions themselves, such as presence, actions, and words, can not only influence our perceptions but also determine the progress of an encounter by serving as emergent coordinating processes [23]. Each agent involved in this coupling contributes to its coregulation, but the interaction process also self-organizes and self-maintains. This leads to the fact that sometimes, it continues in unintended ways. For example, when we bump into each other on a narrow street and both parties want to give way, it often happens that we end up moving left and right several times together. This is the relational dynamics of the interaction process at work. In this process, social interaction involves a double influence: coordination impacts the course of the encounter, and the dynamics of the encounter affect the chances of coordination.

Participatory sense-making is based on participants' ability to actively and adaptively engage with others in social interactions. Thus, the flexibility in navigating the patterns and variations of social dynamics influenced by other individuals' actions, which is called *social skills*, is unignorable [22]. In particular, rhythm capacity, regarding timing and coordination, plays a crucial role in social skills. It is the capacity to seamlessly transition between different interaction rhythms or achieve harmonious mutual coordination. Research has shown that individuals who are less rhythmically able may struggle to engage with their interaction partner [77]. Although more research is necessary, current evidence suggests that people with autism encounter difficulties related to interaction timing [22]. If the timing of the interaction is awkward and neither partner can adapt flexibly to each other's timing, it can lead to low-quality rhythmic capacities and ultimately result in problems during the interaction.

Sustained participatory sensemaking requires a careful balance between the ongoing becomings of both "known" and "knower" [22]. If there is too much interference with what is already known, it becomes over-determined and risks losing its essence, leading to a lack of true understanding or even misunderstandings. On the other hand, if there is too little interference to the point of disengagement, we lose touch with it and under-determine its meaning. This dynamic balancing act is also referred to as knowing as letting be, which only occurs in a relation.

2.1.3 Coginitivism and Phenomenology

Cognitivism is a theory that sees the mind as software operating on the brain's hardware [86]. The perspective is rooted in a Cartesian western worldview that highlights the importance of the mind, as well as the divisions between subject and object, and mind and body [79]. Cognitivism typically perceives the mind to be located inside the brain and represents the external world of physical objects and other individuals [86]. Furthermore, it embraces the concept of interacting with the world as a predominantly sequential process: first perceiving the environment, then internally processing information to gain comprehension (adjusting internal representation), which subsequently leads to devising an action plan executed by the motor system.

The notion of embodiment has its roots in phenomenology and enactment. For instance, Martin Heidegger emphasised the concept of being-in-the-world, which he referred to as "thrownness" [40]. This means that we find ourselves already thrown into an existing world and must navigate it without complete knowledge of the consequences of our actions. Our decisions are always based on dynamic and incomplete information around us. To understand existence, we need to actively engage with our surroundings and embrace direct experiences in an open manner. On the other hand, Merleau Ponty suggests that meaning arises through the interaction between the human body and the living world [54, 46], emphasising the importance of the body in perception.

Phenomenology and embodied theories emerged as a response to the cognitive view of the mind, aiming to transcend its Cartesian dualisms. These theories depict human sense-making and associated behaviour as a coordination process facilitated by a self-organising network comprising the brain, environment, and the active body [86]. This embodied and situated self-organising sense-making network includes bodily constraints, homeostatic processes, and dynamic interactions between the active body and both physical and social environments (also known as lifeworld).

2.2 Implications of Embodied and Enactive Theories

Historically, the development of embodied theory in interaction design can be traced back to 1986 when Winograd and Flores proposed an alternative view on human-computer interaction based on Heidegger's phenomenology theory [92, 40]. Later, Ed Hutchins introduced the concept of distributed cognition, which gained popularity in interaction design [47]. This perspective shows how cognitive processes are distributed among people and tools. At the same time, the term ubiquitous computing was introduced by Mark Weiser envisioning hybrid spaces with embedded digital technology [90]. In this vision, ubiquitous computers will solve the issue of information overload. Instead of humans having to adapt to machines, these computers will be designed to integrate into our environment seamlessly. This will make using a computer as enjoyable and refreshing as taking a walk in the woods. Nowadays, HCI research is undergoing a transformation from screen-based interactions to tangible and embodied experiences of digital information [85]. This shift is driven by ongoing developments in embodied, distributed, and situated cognition [80, 85].

2.2.1 Diversity Computing Framework

According to participatory sense-making, actual interactions can modulate how individuals enter social interaction and, at the same time, have the responsibility (at least part of) to affect the social encounters [23]. This theory provides the foundation for DivComp - a framework that emphasises the demands for designing new computing devices and inviting individuals from diverse backgrounds to participate in an active and reflective process of meaning-making [29].

The DivComp framework builds upon extensive research on the embodied and situated nature of technology-mediated practice. Specifically, it addresses diversity-related issues such as neurodiversity. First, DivComp emphasises the importance of human-human interaction mediated by technology, rather than solely focusing on human-computer interaction [29]. This is based on recognising that each individual is unique and, therefore encourages people to actively participate in meaning-making. Second, it emphasises the importance of creating a third space where a DivComp device can facilitate productive discussions and creative exploration of shared norms and meanings. This includes requirements such as making sure everyone can participate and providing opportunities for constructive disagreements, which are inevitable. Last but not least, a DivComp device should support iterative exploration. Ideally, each round of activity with the DivComp device would involve participants in different information-seeking activities, resulting in changes for both the users and the device.

2.2.2 Impacts on Interaction, Act of Design and Support

Overall, the embodied and enactive cognition theory can inform the system design from the following aspects: interaction (including both human-to-human and human-to-product interaction), the act of designing, and support.

Embodiment theory implicates us to explore multiple senses or unrepresented aspects of the body. Sight is the most common sense, which is, to some extent, overused. However, hearing and touch are waiting for more exploration. The virtual worlds of software are realms of cognition, where ideas and concepts exist on screen without physical substance. On the contrary, physical objects possess weight, texture, and surface, which is referred to as tangibility in design terminology. Without tangibility, all the pleasure of manipulating an object, feeling its weight and texture, and being in control will disappear. Therefore, exploring the tangibility aspect can be a promising direction for human-to-product interaction. In addition to these, the human body can also perceive more subtle things such as balance (which is related to the vestibular sense) and situational awareness. These complex aspects are often overlooked when designing innovative ways of perception, but they hold great potential for unexpected outcomes.

According to the DivComp framework, such an interactive system which supports social connections should engage the participants together and make sure the person-to-person interaction is prioritised and prevent solely interacting with the technology without noticing others' presence. At the beginning stage of the interaction, it is supposed to have an immediate impact on the space and trigger coordination between participants. What's more, it should design an exploration process with iterative mutual understanding formation. Users can take an opportunistic approach, changing and re-specifying their objectives or their strategies of exploration. This can be accomplished through various layers of design, either temporal or spatial.

Regarding the act of designing, making is centralised. Only by making experienceable prototypes and placing them in the actual scenario can designers observe how meaning was generated in interaction in a specific socially situated context. Furthermore, making can also provide valuable insight for the designer in an iterative mutual understanding process. On the one hand, hands-on making fuels creative inspiration through tangibility and yields the designer's deeper understanding of the built structure. On the other hand, when making prototypes, intuition can be easily introduced into the system to deal with complex matters and create meanings.

To support the act of making in designing and embodied sensemaking in interaction, a series of supports such as methods, processes, techniques and tools should be adopted. These methods should combine making and thinking in an ordered way and facilitate reflection to connect intuitive and analytical insights. The process needs to balance multiple activities, such as conceptualising, creating, validating, and analysing, and encourage researchers to switch between different activities freely. Choices of tools are not limited. Portable electronics are prioritised due to their flexibility and freedom to sculpt the vision. Finally, real environments, which are meaningful parts of people's lives, appear to be more aligned with and may offer better opportunities for exploring the concept of embodiment compared to laboratories. Therefore, validating the designs in the wild and engaging the real users are crucial.

2.2.3 Participatory Sense-making in Double Empathy Problem

Participatory Sensemaking concerns the embodiment and situatedness of the autistic person. Such theories depict human sense-making and associated behaviour as a coordination process facilitated by a self-organising network comprising the brain, environment, and the active body [86]. This means each self-organising network is unique. Since this process can be meaningful for neurotypical individuals, this should be applied to autistic individuals as well. How autistic people perceive, move and emote is supposed to be intrinsically meaningful to themselves, though not necessarily meaningful to others. Such differences can be interpreted as different ways of perceiving or as different strategies for coping with the world.

When dealing with the Double Empathy Problem, participatory sensemaking theories provide an embodied and social-interaction-focused account that is different from other autism explanatory theories such as ToM, WCC, and EF [61]. Traditional theory merely focuses on autistic perception. However, according to participatory sensemaking, sensorimotor differences involving both temporal aspects of perception and movements are seen as causes for different sense-making between autistic and neurotypical individuals. Fundamentally, some individuals with autism may have sensory processing differences that affect their perception of touch, taste, smell, and other bodily sensations [43]. Regarding the timing aspects, rhythmic capacity differences can cause dynamic issues. In a neurodiverse conversation, one or both parties may not have the flexibility to adapt to the other's timing. This leads to the hamper in the rise and maintenance of sense-making in neurodiverse dyadic interactions.

What's more, under the guidance of such theories, interactive factors, but not individual deficits, play an explanatory role even in investigating social deficits. It is known that sensory hyper- and hypo-sensitivities and particular patterns of behaviours of autistic people can greatly affect the success of an interaction. However, when autistic individuals experience sensory overload due to external stimuli and struggle to regulate it, we need to realize that neurotypical individuals may not understand what sensory overload feels like. Such an explanation brings a new perspective. Furthermore, reduced interactional synchrony is linked to weaker social skills among autistic participants. For instance, individuals with autism exhibit greater variability in their tapping or knocking rhythms compared to neurotypical participants when attempting to synchronise with an audio stimulus. But if we see it as awkwardness caused by both motor and timing differences between different neurotypes, we put the emphasis on the interaction instead of the participants.

All these factors will affect social interaction dynamics, particularly the coordination quality, frequency of breakdowns, ability to repair them, and the experiences of both neurotypical and neurodivergent individuals. Combining existing knowledge of the autism community and understanding the Double Empathy Problem through participatory sensemaking, new challenges and additional requirements arise for system design.

First, diverging communication styles can bring confusion and, therefore, become an

Table 2.1: Principles for design and research based on embodied and enactive theories

Category	**Principles**
Interaction/System Design	Senses: explore multiple senses or unrepresented aspects of the body
	Mediator: person-to-person dyadic interaction is prioritised where system serves as mediator
	Structure: offer structures without relying on complex behaviour or language interpretation
	Commonality: explore a universal communication method for mutual information seeking
Act of Design	making experienceable prototypes
	balance multiple activities and facilitate reflection to connect intuitive and analytical insights
	portable electronics are prioritised due to their flexibility and freedom
Validation of Design	validating the designs in the wild
	provide resources during or after instances of breakdowns

obstacle to neurodivergent communication. This system design is supposed to *explore a universal communication method* which offers a safe and free way for individuals, especially neurodivergent participants, to seek information to understand social encounters better. Common features and elements, such as playfulness, that frequently occur in autism intervention technologies should be considered.

Additionally, ambiguous rules mostly developed in neurotypical interactions can be misunderstood by neurodivergent individuals, and neurotypical individuals can not even notice the struggle of neurodivergent. To overcome these challenges, the designed machine should offer structures without relying on complex behaviour or language interpretation. This prevents participants from being influenced by dominant norms in interaction, allowing them to be themselves. It does not mean that neurotypical people should unilaterally adapt to neurodivergent people. It is more like a growing chance for each other to learn more about the mystery of the world.

Lastly, since we can anticipate a high occurrence of breakdowns during the interaction, it is crucial to provide resources during or after instances of disruptive behaviour. For example, some toys used to soothe emotions should be prepared in advance to provide support when the participating children show anxiety reactions. Adjustments to procedures or experiments should be made in response to the needs of the autism community. Furthermore, therapists and other support teams should be on site when conducting workshops.

Overall, the implications of the embodied and enactive theories for this study can be summarised into three parts with nine requirements in Table 2.1.

Chapter 3

Related Work

In this chapter, we will focus on system design and examine a series of cases from the four requirements in the category *Interaction/System Design* proposed in the Chapter 2: senses, mediator, structure and commonality (see Table 2.1). In the first section, cases designed for multiple senses and facilitate person-to-person interaction will be introduced. The strategies summarised are applicable to most people when building social connections. In the second section, structure and commonality are described with examples because they are especially important for the autistic community.

3.1 TEIs for Social Connections

To go beyond the traditional Graphical User Interface (GUI) and explore new ways of interaction, there has been a growing popularity in designing and developing tangible technologies. Based on the development of Tangible User Interface (TUI) [84], tangibly embodied embedded interactions (TEIs) have evolved [85, 27].

TEIs include various systems and interfaces that possess characteristics such as tangibility, spatiality, embodiment, and expressiveness. These characteristics make TEIs suitable for promoting movement among autistic children by allowing them to physically engage with their surroundings. Through the embodiment feature, physical activities occur naturally both in the physical space and metaphorically in the digital realm. They are so-called hybrids, or physical-digital artefacts, which have the ability to achieve a potential that exceeds the combined capabilities of their digital and physical components [73].

Apart from the sensorimotor characteristics, TEI systems designed for social connectedness are representative of satisfying the participatory sensemaking demands. They can not only help maintain and strengthen relationships with loved ones, friends, and caregivers but also provide opportunities for engaging in social activities and forming new connections [85].

3.1.1 Visual Stimuli and Body Movements

Overall, visual stimuli, especially display, are the most commonly used form of digital interaction modality [27]. Usually, light functions mainly as it captures attention. Projections, screens, and other user interfaces provide highly specific visual feedback, which has a greater potential for communicating with the user. Rather than traditional touching screens, these TEIs systems heavily depend on bodily movements.

Storytelling is widely used in such visual systems to facilitate continuing engagement and create beauty and fun for participants. For instance, "Choreographies for Humans

FIGURE 3.1: Project "Choreographies for Humans and Stars". Left: Participants dancing together. Right: The Choreographies created by Dana Gingras [3]

FIGURE 3.2: Goddess Re:Membered, by John Bellona

and Stars" (Figure ??) is a project that utilises projection technology to enhance body movement, specifically dance [3]. The projections display illustrations and instructions for the choreography, which are impacted and transformed by participants moving in sync with the animation. This project was created with choreographer Dana Gingras to compose a dance inspired by physics laws that guide collective movement while allowing personal interpretations. With the changing scenes and guidance of the story, unfamiliar people are invited to join this dance.

Additionally, John Bellona designed an interactive mirror that uses video displays and created an installation called "Goddess Re:Membered" (Figure 3.2) that encourages multiple people to interact within the space. It generates a multimedia response to a classic silent film called The Goddess. Through public interactions of users inside the space, clues to distant memories are revealed through the triggering of colour, sound, and video masks. With more people in the room, the more pieces of the film will be shown, and the closer they are to the screen, then the bigger scope of the film will be shown.

Some interesting feedback loops can be identified here. For both of the projects, with instant feedback on the screen, participants can immediately identify the common impact of their own movements and others'. This creates a peripheral perception of the presence of others and triggers the functional coordination of participatory sensemaking [23]. However, these two examples employed different strategies to further explore mutual interests. On the one hand, "Goddess Re:Membered" focuses on amplifying the perception of others by adding plots when the number of participants accumulates. It's more like a passive strategy

FIGURE 3.3: Participants experiencing CRDL [4]

for participants to collaborate using their body or presence to dig out more content of the film. On the contrary, "Choreographies for Humans and Stars" uses the autonomy of the interaction more proactively. The paired dance itself may be difficult to start, but once it begins, it creates a strong resistance for participants to actively withdraw and motivates them to continue watching the plot and following new instructions. The curiosity about new instructions further engages participants in another round of dancing, creating intimacy through proximity and physical contact.

3.1.2 Tangibility and Proxemics

Tangibility is another important modality. For tangibility, touching is in some instances still an arguably mainstream approach to embodiment [94]. CRDL (Figure 3.3) is a care instrument designed to create impactful connections between people [4], which can translate touches between people into sounds. It recognises the type of touch and adjusts the produced sound accordingly. In a study of one-to-one interactions, professionals and family members reported that using CRDL with individuals with dementia was a positive experience. They found the interaction to be pleasant and familiar and felt that they were able to establish better communication with the person with dementia [81].

Different from body movement, touch emphasises more on the perception of the presence. This kind of direct stimulation, like dynamic touching and music, is crucial for helping the participants perceive interactions between themselves and others. Social touch can facilitate the formation and reinforcement of social bonds. On the one hand, interpersonal touch is rich in expression and it can create an immersive experience with appropriate factors such as type of touch, location, social connection, and situation. On the other hand, touch can enhance the metaphorical concept of warmth by evoking both physical and psychological sensations simultaneously.

The mere act of being physically close is closely associated with social intimacy [64]. For instance, Musical Embrace [44] is a digital research game that showcases the effective use of social awkwardness as a gameplay element (Figure 3.4). In this game, two players control a hanging pillow with their torsos to navigate a virtual world filled with sound sources. This

FIGURE 3.4: *Musical Embrace* makes use of social awkwardness as a gameplay element [44]

FIGURE 3.5: Music Swing

project explores uncomfortable interactions and embraces social awkwardness in computer games, highlighting their potential advantages. It creates a unique atmosphere of both awkwardness and intimate closeness within the game's playful context.

Allowing someone into a personal or intimate space signals inclusion and closeness, thus potentially facilitating interpersonal warmth and positive attitudes. Furthermore, the power of affective touch for creating interpersonal warmth and intimacy is related to proxemics too [12], as touching requires entering each other's intimate personal space. However, it is also worth noting that when two people are forced to be closer than they are comfortable with, they may compensate by creating distance in other ways to restore a sense of balance in their perceived level of intimacy [94].

3.1.3 Shared Experience and Synchronisation

Having a shared experience with another person is also a powerful way to feel more connected to them. Shared exploratory experiences foster collaboration and friendship among participants. For instance, Musical Swings is a public installation consisting of 21 swings [5]. As shown in Figure3.5, each swing triggers notes from classical instruments such as the piano, guitar, harp, and vibraphone. The higher the swing goes, the higher the note it produces. When all the swings move together in harmony, they create a musical composition that allows for unique melodies to emerge when participants cooperate.

This shared experience can also be accomplished through synchronising our movement, textile stimulation or physiological elements [94]. In The Machine to be Another [2] two individuals wearing a VR headset with a camera exchange their bodily perspectives. Through synchronised movement, they experience the sensation of being in each other's bodies. In the exhale installation [70] participants can share their breathing with each other initiated through touch and felt as a movement of air on the skin of their legs (Figure 3.6). Such spontaneous breathing synchronisation enabled a sense of intimacy.

FIGURE 3.6: Exhale: breath between bodies [70]

Movement synchronisation is a common aspect of cultural activities involving rhythms, such as dancing and team sports. When our bodily states align visibly, the distinction between self and others becomes blurred, as we perceive our own movements or feelings in those around us. Physiological synchronisation can support connection through a much more intimate interaction than movement synchrony as it also engages the strategy of biofeedback sharing. Such tactile-based feedback and synchronisation is more likely to bring a deeper sense of intimate connection than the challenge-based mechanic of gamified synchronisation and systems' reliance on visual feedback.

3.2 Structure and Commonality

For neurodiverse interaction, further requirements such as "offer structures" and "explore a universal communication method" were suggested. Some can be found in projects for autistic research. One of these projects, *OutsideTheBox*, led by Frauenberger et al. [31], was highly representative. The *OutsideTheBox* project aimed to explore how autistic children, aged 6–8 years, can lead the design processes of digital technologies to create smart objects that are meaningful to themselves. It is a collection of multiple cases and sub-projects. DSmart (Figure 3.7) is one of the sub-projects, which is a smart companion looks like a kaleidoscope. It not only provides information about upcoming movies but also offers storytelling prompts. Acting as a conduit between Dean and his surroundings. He can share this system with other children and it enhances control and predictability in their interaction.

The commonality of a tool is related to how much participants' individual understandings overlap and are embraced by each participant. By prompting users to reflect on their

FIGURE 3.7: The prototype of DSmart project [31]

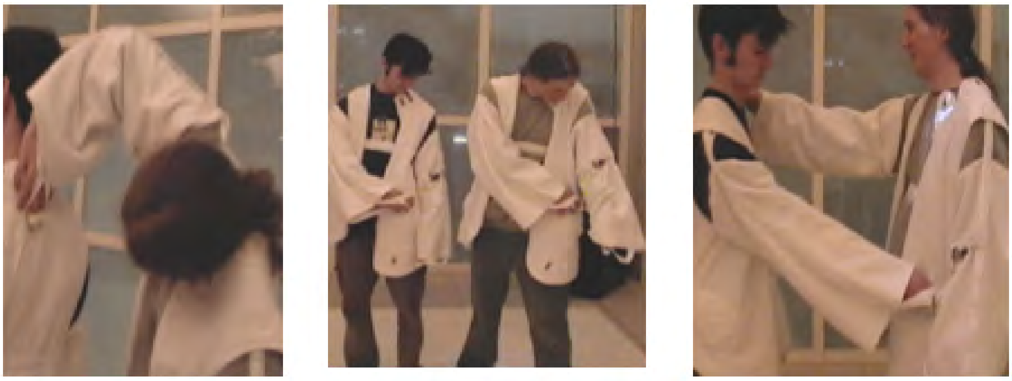

FIGURE 3.8: Gestural Interaction in the *Whisper* Installation [71]

commonalities with other users or humanity as a whole, a sense of connection can be established and nurtured. In Whispers (Figure 3.8), participants wear special garments that allow them to connect and share their biodata [71]. It is achieved by collecting breath and heart rate information using small wearable sensors on their bodies and transmitting the collected data to interconnected devices integrated into the specially designed garment worn by the other person. The experience of others in these systems often feels anonymous, as they are seen as representatives of humanity rather than individuals.

A universal communication method can be achieved by considering some behaviour or expression which can easily arouse misunderstanding and transferring it into sth that is comfortable and enjoyable. Stim4Sound [58, 97] is a project that focuses on two individuals creating sounds using various objects in their everyday lives through common stimulating behaviours like tapping or shaking. As shown in Figure 3.9, it involves a wearable device that records the music produced and also detects specific actions to modify different musical elements, synchronized with movements. With Stim4Sound, participants can collectively redefine these stimming behaviours within a social setting. The included melodies, rhythms, and additional instruments encourage interaction by linking movement to sound. This is also a powerful way to let others learn how we feel thus facilitating self-disclosure.

It is evident that displaying TEIs with embedded games can enhance social interaction by offering participants various choices to create and play together. This is rather effective in social interaction systems involving autistic children. For example, Tovertafel is an interactive projection system that tracks body movements and gestures (Figure 3.10). The whole system is hanging from the ceiling and looks like an enlarged version of the projector. Whether it's projected onto a table and activated by hand movement, or onto a floor and used with one's entire body, the system creates a lot of games that are therapeutic and fun. The targeted user group of Tovertafel include seniors with dementia, adults with intellectual disabilities and children with special needs. Similarly, STOMP [93] would

FIGURE 3.9: The product model of Stim4Sound [97]

project the game space onto a mat, which children would then interact with by stepping, touching or walking on the mat (Figure 3.11). The floor mat acts as both input and output of digital information.

FIGURE 3.10: Left: Tovertafel System. Right: Tovertafel games for kindergarten children [11]

3.3 Implications of Related Work

3.3.1 Strategies for building Connections

In the previous section, we gained many insights through case analysis and discussed their application in practical situations. Here, I will summarize and categorize these strategies.

Summary of general strategies for building connections

- Increasing awareness of others
- Interpersonal touch for intimacy
- Create a chance for physical proximity

FIGURE 3.11: Participation modes available through Stomp [94]

- Engaging in shared exploratory experiences
- Synchronizing movement, tactile stimulation, or physiological factors
- Encouraging users to contemplate their similarities with other users or humanity as a whole

Summary of additional strategies for double empathy problems

- Structure
  - Storytelling
  - Game mechanics
  - Space limited environment
- Commonalities
  - Bio data such as Breath and heart rate
  - Simple behaviour or expression with diverging understanding

3.3.2 Selection of Tools and Technologies

The selection of tools and technologies is connected to the actual design practice, which can only be learned from concrete system designs. These selected related works offer us a wide range of tools with potential. To support the study, how these technologies are connected to the theories and materialisation of embodiment is demonstrated here.

Sensors are the most noticeable technological aspect of embodiment as they allow the body to be sensed in different ways. Computer vision or IMU sensors can detect body movement, from presence to subtle gestures. Auditory data are usually recorded using microphones and The body tangibility can be detected through touch sensors integrated into wearables. Body signals can be detected by using physiological sensors of varying complexity levels (such as ECG, EMG, and EEG), as well as simpler chest sensors for detecting breathing. However, despite being less diverse and emphasised in the chosen studies, the significance of actuators in embodying a concept is equally important as sensors. In terms of visual stimuli, light serves for illumination purposes but primarily for projections and other types of displays. Sound is employed to play music, sound effects, or ambient sounds. Robotics and other mechanic structures (e.g. the airbags in project *exhale*), on the other hand, are utilised to generate artificial movement and physicality.

The body can be detected in its multiple aspects, but this detection is only of significance when it affects the environment, and therefore also affects back the body - a feedback loop constituted by sensor input and actuator output connections. through processors like computers and microcontrollers, using either wired or wireless communication technology, sensor and actuator technologies make new interactions possible. Except computers, Affordable and versatile devices such as Raspberry Pis and Arduinos make technological exploration possible, enabling the discovery of new materials for interaction and body sensing. These devices are compact, energy-efficient, capable of processing sensor data, communicating with other devices, and controlling actuators when integrated into objects.

In conclusion, all the selected examples share a common feature: they create smooth full loops with sensors, actuators, and processors. What's even more important is that in these loops, sensors and actuators are conceptually inseparable since action and perception go hand in hand. This allows for a sensorimotor coupling between the body and the environment to be achieved. For social situatedness, shared sense-making is attempted by sharing or exchanging sensor input data, actuator output or both. Additionally, integrating the input data and processing it into a more complex output can improve the level of participation, which leads to higher chances for shared meaning to arise. This is hard to achieve especially considering the commonality principle. But in the project Musical Swings, a good balance was achieved. Some of them also developed a mixed mechanism to encourage users to participate in each other's couplings. For example, in Crdl, the music output is the result of the combined effect of all touch positions and movements. However, the construction of the loop is on the premise of people touching each other as well as the instrument. This immediate impact on the environment (from silent to music) by touching can trigger coordination between participants and encourage them to stay in interaction.

Chapter 4

Methodology

4.1 Methods

In this section, methods are suggested to deal with the stakeholders most relevant to this study: researcher, designer and user. Among them, Research through Design methods provides guidance on conducting research by integrating design and balancing the roles of a designer and a researcher. The combination of the UCD and Co-design methods, on the other hand, helps to express the positioning of user participation in this project. The goal of this project was to organise Co-design workshops. However, due to the limited communication skills of the participants, we need to define it in a more accurate manner.

4.1.1 Relations Between Design and Research

There are several different perspectives to deal with the relations between design and research. Some of them think research and design are the same activities, doing research is doing design. However, a more widely accepted point of view is that doing research is a part of doing design. Many designers would conduct studies to learn specific situations for their design. Scientific and technological information is gathered and applied to learn specific information for design purposes. Design is then informed by research.

Research and design both aim to create something new, building on existing knowledge. Both activities contain parts of the other. However, there are distinct differences between them at various levels [37]. Firstly, the practical purpose of research is generally to acquire general knowledge, whereas design seeks to provide specific solutions within concrete circumstances. Secondly, research and design yield different outcomes. General knowledge is typically presented at a cognitive level through theories and publications, while specific solutions are more concretely represented by tangible objects or virtual applications. The outcome of research tends to be more abstracted while design is situated in practical application. Thirdly, research typically involves long-term investigative processes, while design focuses on creating realisations or constructions that are usually short-term.

4.1.2 RtD Methods

In this study, the relationship between design and research is that research is informed by design. This aligns with my research question: "How can we design interactive systems to foster neurodiverse social connections in support of embodied and enactive cognition?" The emphasis is on sharing the insights gained from the design and thinking process. Accordingly, a Research through Design (RtD) method is applied. RtD is a scientific approach first proposed by Frayling [32]. He utilised valuable insights from design practice to enhance comprehension of complex and forward-thinking issues in the design field. Nowadays, it is particularly appealing in fields such as Human-computer Interaction (HCI) and Interaction Design (IxD). New possibilities and complexities presented by information technology bring challenges to shaping abstract problems. RtD recognises and values the contribution of professional practice in design professions to knowledge generation. This includes gaining a practical understanding of complex situations like the double empathy problems, framing and reframing them, and iteratively developing prototypes to address them. In practice, the researcher is at the same time playing the role of a designer. He/she develops new products, experiments with materials and processes and simultaneously, attempts to recast the design aspect of creation as research. The underlying belief is that valuable insights can be gained from both the final design and the process itself, which can then be effectively communicated and shared with others.

RtD is applied in this study instead of traditional research due to both the creative purpose and multidisciplinary background of this project. While traditional research aims to understand the world as it is, RtD focuses on studying the potential impact of an effect in a future scenario [19, 46], e.g. what occurs when an interactive system is integrated into a communication process involving neurodiverse individuals? What's more, this project involves collaborations between the university (University of Twente) and a professional design agency/industrial partner (Crdl). On the one hand, this close connection to the creative industry provides a foundation for criticality and experimentation in the realm of knowledge production, which is essential for the application of RtD methods. On the other hand, RtD methods provide a blueprint to organise the varied and complicated activities together and balance the expectations of both groups.

4.1.3 Co-design and UCD Methods

To address the dynamics between users, products, and design researchers, a combination of UCD[1] and Co-design[2] approaches are applied in this study.

Designing is an activity that always serves a specific group of users. If we want to design the futures we desire, it is essential for those whose futures are impacted to participate in the design process actively. This is not only a moral requirement but also has many benefits. Actually, user participation plays a central role in shaping the understandings and practices that define current trends in areas like design thinking and user-driven innovation. It acknowledged that the use and impact of technologies are influenced by their context. This complements the rejection of technology-driven formalisms and rationalist models focusing solely on individual tasks. Furthermore, designing technology with users' direct involvement is particularly valuable in an autistic children context. It not only can create meaningful technology but also enriches and empowers participants in the design process [50, 30].

Methods like UCD and Co-design both value user participation. In co-design, the participation of the user is more active and direct, which goes beyond mere "involvement". It entails investigating, reflecting upon, understanding, establishing, developing, and supporting mutual learning processes that occur among participants in collective "reflection-

[1] As defined by the International Organization for Standardization, user-centred design, also termed "human-centred design", is an "approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques" [48].

[2] Co-design, previously known as participatory design, can be seen as an approach focusing on collaboration between trained designers and non-designers, especially users, during the design development process [69].

in-action" during the design process [65]. This is highly effective in developing technology for marginalised groups with different life experiences from designers and researchers. However, one of the greatest challenges in co-design projects is to ensure that they can last for a long enough period of time to fully explore mutual learning in the development and implementation processes of new products and contexts, as well as reflect on and evaluate the process and its outcomes. Due to the limitation of this project duration, the complete process of typical co-design is unapproachable. At the same time, the unique characteristics of individuals with autism pose specific challenges when it comes to involving them in design work [31]. Factors such as special interests, rigidity, perfectionism, and the socially demanding nature of design need to be carefully considered. It is necessary to adapt and reinterpret co-design methods when working with autistic children. For example, considering the speciality of the user groups involved (autistic children and neurotypical adults), the designer should decide when the involvement of each stakeholder is appropriate according to the needs of the project. In conclusion, due to time and group factors, the user participation level in this study is limited. It can no longer be counted as a full co-design method but it goes beyond the UCD method. Therefore, it is positioned between user-centred design (UCD) and co-design modes.

Co-design methods still guide a lot for this project about dealing with the relationship between designer and user in design practice. At the core of co-design is active user participation - directly involving people in the design of tools, products or environment [69, 65]. It requires me to continuously develop processes, tools, and methods that facilitate active and engaged participation in design activities. Additionally, practice is another key element in co-design, serving as an essential epistemological component [65]. This practice element is different from the making principle about the act of design. It indicates that the design can only be completed during usage in workshops. Placing prototypes in the actual scenario is emphasised. Last but not least, co-design projects are always driven by ongoing and systematic reflection on how to involve users as full partners in the design process [65]. It brought about further contemplation regarding the engagement in reflection activities, beyond just reflecting on design decisions and research questions.

4.2 Process

4.2.1 Swimming Pool Framework for Activities

At the beginning of this study, a framework named "Swimming Pool" was suggested by Jelle van Dijk during one meeting. Triggered by my question about how RtD is actually in use, Jelle says:

> Doing such research is like swimming in a pool with multiple lanes. You switch from one lane to another and switch back periodically. These lanes can be design, technology, workshops...... Be careful not to spend too much time merely in one lane.

This framework was not a formal one which can be found in articles, but very effective for directing such projects. I later defined this swimming pool with five swimming lanes, including ideation, design, implementation, workshop, and theory development. The whole process of the project looks like this (Figure 4.1), in which time is unevenly located for theories at the beginning and final phases of the project.

In ideation, my ideas usually come up through reading, communicating, collecting cases, experiencing exhibitions, etc. It demands me to sharpen my senses and make use of my

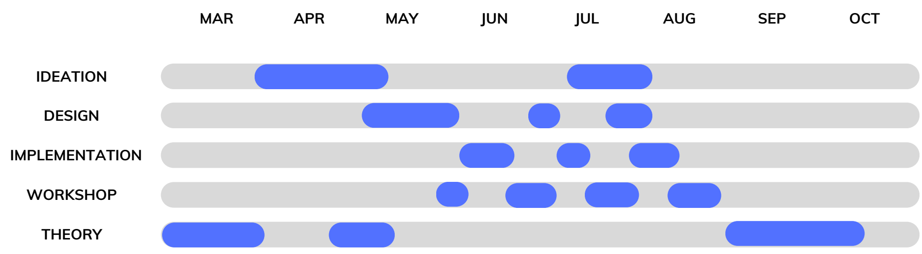

FIGURE 4.1: The swimming pool framework of the activities in this project

own life experience to incubate innovative ideas. During the design process, more logical hypotheses are suggested and ideas are selected and further developed into the forms of sketches, blueprints or proposals. In the implementation phase, technology is focused. In this phase, physical realisations are made. Additionally, exploration of new materials and learning how to use certain digital tools are also considered part of it.

Overall, the workshop activity is a hypothesis-testing process. It is composed of three stages: plan, execution, and analysis. The act of planning is to transfer the hypotheses into steps available for workshop organisation. Execution, which is the actual organisation of the workshop, is an explorative confrontation with real-world situations. The complex variables and the nature of this research often lead to the unfolding of the workshops in a way that is different from what was initially envisioned. These factors are considered in the analysis phase combined with valid observations.

Theory development is then a process of making sense of what happened in the workshops and integrating it into existing theories or hypotheses. This can cause improvement or update of our principles and strategies, as well as tools and methods for design, which ultimately compose the answer to my research questions.

In summary, the organisation of Chapter 6 and Chapter 7 is based on the division of activities within this framework.

4.2.2 Decision-making Process

However, design decisions are often made conditionally – developing design solutions within both models can be seen as a process of making decisions with very limited information. In such a situation, we need a more reliable mechanism to help us make efficient decisions, especially to prevent designers from falling into decision fatigue due to excessive information.

According to Drucker, the decision-making process typically involves two steps [24]. Firstly, it begins not with gathering facts, but with forming one's own insights or hypotheses that still need to be confirmed. Starting from collecting facts is unrealistic because the facts collected will always be based on one's own existing conclusions. Therefore, it's important to understand that we are starting from hypotheses yet to be proven, the hypotheses that do not require debate but must withstand verification. Secondly, further investigation is required to gather the necessary facts and establish measurement standards based on these hypotheses. This involves determining what needs to be observed, studied, and verified in order to acquire and identify the relevant information. This two-step tip was very helpful in balancing my impulse to collect numerous facts without direction during the design process. It provides more structure in the research stage and helps me become efficient by making decisions quickly.

Chapter 5

Workshop Background and Support

5.1 Research Team and Participants

I am conducting independent research as part of a three-student team led by Jelle van Dijk. Three students are studying Interaction Technology and working on their Master's Final Project. They have a general objective: "How can multi-sensory embodied interaction technologies support neurodiverse (dyadic) social interactions?" Each student has a unique research focus in tactile, auditory, or visual aspects of dyadic interaction. Our collaboration includes attending two to three seminars per month, sharing materials and research insights, and co-organizing workshops.

Due to the user-centred and co-design aspects of this research, four workshop sessions were organised from June to August 2023 in De Walnoot [1], a daycare centre in Leiden for children with special needs. In total, seven autistic children and four neurotypical adults (including the researchers who served as participants) participated in all workshops. All children (A, B, C, D, E, F, G) are from the same group[2], between the ages[3] of 6 and 10 and diagnosed with ASD. One teacher who also serves as a play therapist participated in all workshops as a participant (T0), facilitator and security provider. Two other neurotypical participants (T1, T2) and I (R0) are all females aged 25 to 30. Additionally, the table 5.1 contains the participation status of various participants. Before doing the experiments, we obtained approval from the ethics committee to conduct these workshops. Additionally, the participants' guardians provided consent for their representation in video recordings and photos (refer to Appendix A). This was on a voluntary basis and the participants were

[1]The daycare center is there for children from 0 to 18 years who are not (yet) ready for a form of education, who have a developmental delay or an intellectual and/or multiple disability.

[2]De Walnoot has fourteen groups with six to eight children per group. Each group has two facilitators. Additionally, children receive support from various experts as needed. These include behavioural experts, remedial educationalists, speech therapists, physiotherapists, occupational therapists, play therapists, exercise therapists, and paediatricians.

[3]The specific age of each child has not been provided.

TABLE 5.1: Overview of Workshop Participants

Workshop	**Neurodivergent Participants**	**Neurotypical Participants**
Inquiry Workshop	A, B, C, D	T0
Workshop 1	A, B	T0, T1, R0
Workshop 2	B, C	T0, R0
Workshop 3	E, F, G	T0, T2

FIGURE 5.1: The school gymnasium room for all workshops

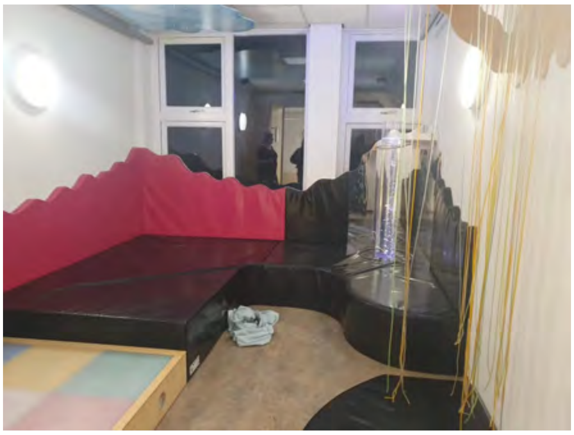

FIGURE 5.2: Quiet rooms designed for children to relax

not provided with any additional compensation.

5.2 Workshop Environment

After establishing a cooperative relationship with the school [4], a visit was made to the school as part of a contextual inquiry. During the visit, we toured the school's facilities and classrooms, met with different groups of children, and had conversations with teachers to discuss the children's specific needs. Based on these discussions, we decided to use the school gymnasium room for our workshops (as shown in Figure 5.1). The room, measuring approximately 25 square meters, is primarily utilised as a children's gym for play and exercise. On the one hand, this room is undisturbed during non-usage time. On the other hand, it has ample space and minimal decoration. To provide readers with an impression of the school environment and the group, some valuable insights are listed here as additional information:

- **Children are heavily relied on routines and structures**. Visualised print-outs of their daily schedules were placed on their classroom doors to further support this

[4] De Walnoot is a daycare center for children who are not (yet) ready for formal education. However, it is referred to as a school here due to researchers' habits. From a certain perspective, children learn important life skills at De Walnoot, which is as important as formal education.

structure. There are designated rooms for specific activities. This separation and organisation helped establish expectations and provided them with a sense of comfort and familiarity.

- **Rich resources are allocated for varied sensory needs.** The school and teachers offered various play elements and spaces, including technology resources. Figure 5.3 illustrates the presence of quiet rooms designed for children to relax under soft lighting and music or interact with interactive devices. Additionally, there is a special education room equipped with dozens of materials and toys for one-to-one educational activities.

- **Special ways of communicating are integrated into daily life.** The teachers emphasised the importance of showing and performing rather than simply telling things to the children. When guiding the children to another room, the teacher would naturally use a toy that represents the room (e.g. a football for the gym) to indicate their intention. This approach helped the children better comprehend instructions during activities.

- **Screen-based interactions have become dominant in education.** Tablets are commonly used among children due to their widespread usage inside and outside of school. Some groups use tablets as an educational tool with images of teaching content (e.g. dishes and spoons when teaching them dining skills). Some of the children were non-verbal to varying degrees, relying on tablets to interact with their peers and teachers.

- **Children's reactions to interactive games are polarising.** During the visit, we had the opportunity to experience the Tovertafel system [11] in a small room. Through inquiries, we learned that this system is used during specific game times, usually 30 minutes. Different children have different reactions to this gaming system - some are particularly enthusiastic about certain games, while others prefer to stay in a corner and not participate at all.

5.3 Inquiry Workshop

After the first visit to the school, two other researchers in the team organised a workshop to test their systems. While assisting in the organisation of this workshop, I took this opportunity to observe and understand it as a deeper inquiry workshop with different mediated systems at present. One researcher focused on haptic feedback, especially vibration. She provided on-the-table toys that could vibrate when connected buttons were pushed. There were several different feedback loops between the button box and the toys. The other researcher focused on music therapy and sound-related mediated systems. She made a series of different music, according to her observation, with Ableton software on a laptop and played them with a speaker. The insights gained from the inquiry workshop were integrated into the implementation of the Nudgo system's wall form design.

5.3.1 Overview

This workshop has two sessions. In each session, the teacher introduced two children into the room[5], and then the children would participate in the movement-and-sound system in-

[5] Originally, the plan was for each child to participate individually. However, since these two children are brothers and deeply attached to each other, the teacher made an impromptu decision to allow them to

teraction first and the haptic interaction afterwards. In the interaction involving movement and sound, the teacher played multiple roles as a participant, facilitator, and supervisor for the children. However, in haptic interaction, the teacher primarily acts as a facilitator (guiding children to touch) as well as a supervisor. The total duration of the workshop was 45 minutes, including the breaks in between. The average duration of the movement-and-sound interaction was 5-10 minutes, while the haptic touch interaction lasted for 1-3 minutes. The interview afterwards with the teacher, on the other hand, lasted about 10-15 minutes.

The workshop had a generally harmonious and lively atmosphere. Firstly, it is evident that there was a phase for participants adjusting to the unfamiliar environment, including new people and devices. Overall, when all the participants entered the room, they displayed no specific signs of fear. All three researchers sat either on chairs or on the ground, remaining still and quiet to minimise distractions for the children. During the sessions, the primary interaction occurred between Teacher T0 and Children A, B, C, and D. Additionally, except for toys used in tactile research, some equipment such as computers and cameras, as well as existing instruments like the slide at the venue, are unavoidable. However, unexpected yet interesting phenomena can also be observed due to the existence of these items.

5.3.2 Observation and Insights

The curiosity and calmness shown in the behaviours of the children were unexpected. When entering the room, all the children walked straight towards the people or objects in the room and looked around curiously at the researchers and the equipment. They generally moved on to the next activity within one minute, such as climbing on the slide in the room or touching the teacher with their hands. Most children showed obvious interest in computers. Three of them (A, B, C) approached closely to check the computer screens held by researchers multiple times during the session. The overall curiosity and calmness displayed in children's behaviour create a positive foundation for further research. To some extent, it relieved the tension, further changing the bias of researchers, and enabling me to adopt a more open attitude. However, at the same time, it is confusing whether this is just a relatively special case, which makes further observation necessary.

Additionally, synchronisation in movements was observed during the movement-and-sound system interaction. Participant A imitated the teacher T0 a lot and the teacher also imitated back. They performed a stationary rotation with one hand high and the other low, while simultaneously chasing each other in forward and backward movements, as well as walking in circles around the area. The roles of initiator and follower (imitator) naturally switched several times during this period, demonstrating relatively smooth coordination. And when the music became lively, their movements also became intense, and both A and T0 laughed loudly. This seems to reject the perspective that autistic individuals have difficulty adaptively engaging other's social dynamics and thus have a low rhythmic capacity [22].

However, the case of participant A and T0 is the only case in this workshop that shows very high flexibility and engagement. Other participants are more interested in their own special ways of playing. Child B had a special fondness for sports equipment at this location throughout the session; most of his time was spent climbing up slides alone and sliding down repetitively. Child C paid a lot of attention to the researchers' personal belongings which were clustered on a bench on the side. Based on the discussion with the teacher, the

participate together..

FIGURE 5.3: The girl sits next to the researcher pointing towards the laptop screen

exception of A's high engagement is related to his preference for sound sensory input and dancing activity. This finding supports that sensory processing differences significantly impact participants' engagement in an interaction. It seems that neurotypical people are not so picky about specific bodily sensations, while the neurodivergent group shows a polarised attitude towards one sensation. If we design a system that does not cater specifically to one individual, it is better to include multiple sensory stimulations in order to avoid complete indifference.

There was an unexpected discovery near the end of the workshop. As shown in Figure 5.3, Participant C paid strong attention to the computer. She did not mind being physically very close and almost touching when she sat next to the researcher to look at the laptop screen. She attempted to indicate specific interface elements on the screen, and the researcher promptly clicked on the element she pointed at to play a particular music. This created an interactive loop that made it seem as though she could control the laptop. This behaviour was repeated multiple times with different music elements being clicked until she lost interest. She also placed her feet on the speaker, even after the researcher moved it, showing signs of a preference for the sensory experience of vibration. The researcher was very surprised, excited, and fond of this behaviour. She said: "Oh, she is so cute, I felt we were so intimate at that moment..." This finding not only confirms the sensory preference hypothesis but also brings attention to proxemics. It strongly supports the later transformation of spatial forms in the system.

Besides, some behaviours indicating discomfort or nervousness were also observed, although they were not displayed in very intense forms. For example, child D spent the majority of his time during the session pushing T0. Specifically, they made physical contact by holding hands and displayed resistance towards one another. Although T0 continued participating for his benefit, signs of boredom and uneasiness became apparent. D's enthusiasm and sustained focus on this engagement were not being returned. Near the end of the session, D used his hand to hit T0's head a few times, which was immediately gently stopped by T0. In the later interview, T0 said:

> "Well, he loves to have contact, but because it was open, at the end, he touched

me and he hit me, and uhh, it was difficult for him. He needs more structure in that sense ... ... This was nice. But it was, for me also, an open thing, so I don't know if I do (did) it good."

Providing structure is a design principle suggested in the theory chapter to better deal with the burden of ambiguous social rules for neurodivergent individuals. The observation made me realise that such a structure can benefit both parties in a dyadic interaction situation. In addition to bringing clear expectations for neurodivergent participants, it helps release the more "dominant" party's burden of facilitating coordination. The music's characteristics prevent bodies from finding objects to attach or interact with in space. This resulted in people's bodies being suspended throughout the entire area, which places great demands on participants' imagination and self-regulation. It can put pressure on some individuals. On the contrary, a structure can be easily achieved by putting something in between the participants. Tangible objects naturally provide structures both from spatial and chronological aspects. This observation suggests the presence of a physical structural system that inherently provides comfort and a sense of safety.

5.4 Support: Techniques and Tools

In this section, we will introduce the main tools and techniques utilised in the following two chapters (Chapter 6 and Chapter 7) to provide readers with a solid understanding of their functions. These can be categorised into hardware and software components. The hardware section specifically focuses on sensors, while the software section covers programming platforms.

5.4.1 Hardware Support

First, Microsoft Kinects were used in Workshops 1 and 2 because of their strong functionality. Microsoft Kinect is a motion sensor input device that includes an infrared depth-sensing camera and an RGB colour camera [1]. Overall, two versions of Microsoft Kinect Sensors were used, including a Microsoft Azure camera Kinect and a Microsoft Kinect V2 camera [6]. Among them, Azure Kinect is the successor of Kinect V2. Compared to Kinect V2, it supports multiple depth-sensing modes and has better angular resolution (Figure 5.4).

Both the Kinect V2 and Azure Kinect measure the depth based on the Amplitude Modulated Continuous Wave (AMCW) Time-of-Flight (ToF) principle [42, 83]. In such an approach, the camera detects the backscattered light from objects in its field of view, which is emitted by an amplitude-modulated light source embedded. Then the measurement focuses on the phase delay of the amplitude envelope between the emitted and reflected light. Thanks to the AMCW ToF technology, it guarantees highly accurate depth detection in such devices with a distance error of $<$11 mm up to 3.5 m [83]. However, also due to the ToF approach, the Kinects cannot be reliably used in direct sunlight and are, therefore, primarily suitable for indoor applications.

Azure Kinect is not just a promising, small, and versatile device but also comes with software developer kits (SDKs), such as the Sensor SDK and Body Tracking SDK [1]. The Sensor SDK provides low-level sensor access and device configuration, while the Body Tracking SDK provides body segmentation and skeleton for each partial or full body in

[6] In workshop 1, one Kinect Azure and one Kinect V2 were used together. In workshop 2, two Kinect Azure were used together. The original plan was to use two Kinect Azures, but due to limited resources from the Interaction Lab, a Kinect V2 was used as a substitute for the Kinect Azure in workshop 1.

FIGURE 5.4: From left to right:Kinect v1, Kinect v2, Azure Kinect [83]

FIGURE 5.5: The ultrasonic distance sensor

FOV. These features make Azure Kinect extremely useful in tasks such as object recognition, people tracking and detection, and gesture recognition. However, at the same time, it can only be used on Windows System and has a high requirement for a computer's processing capability such as a graphics processing unit (GPU). In workshops 2 and 3, a Lenovo Legion 5 Pro laptop was used as the central hub of data processing and computation due to its excellent computing performance. Specifically, it has an AMD Ryzen 7 5800H mobile processor and a built-in Nvidia RTX3070 graphics card, which makes sure the real-time gesture capturing is smooth.

In Workshop 3, we utilised two HC-SR04 ultrasonic distance sensors instead (Figure 5.5). An ultrasonic sensor is an instrument that measures the distance to an object using ultrasonic sound waves. Each sensor consists of an ultrasonic transmitter, a receiver, and a control circuit [7]. The transmitter sends sound waves above human hearing (at 40kHz) and the receiver catches the echo to measure distance by timing the pulse sent and received. This cost-effective sensor is very tiny and offers non-contact measurement functionality ranging from 2cm to 400cm with an accuracy of up to 3mm. In technology implementation, this sensor is connected to an Arduino UNO, which is a microcontroller board widely used. Due to its low-cost, programmable, and cross-platform features, it can be integrated into a variety of electronic projects.

Special attention should also be given to specific materials, many of which are derived from the initial stages of ideation and exploration. One such material is Polymer-Dispersed Liquid Crystals (PDLC), which can serve as a self-adhesive plastic film for existing glass or be incorporated into glass products like smart windows. I obtained some samples in A4 size from the factory. As shown in the Figure 5.6, when activated, the PDLC material within the LCD film aligns itself in an orderly manner under the influence of an electric field, allowing light to pass through and rendering it transparent. Conversely, when power is switched off, the PDLC material becomes disrupted and fails to arrange properly, resulting in a cloudy state that obstructs visibility.

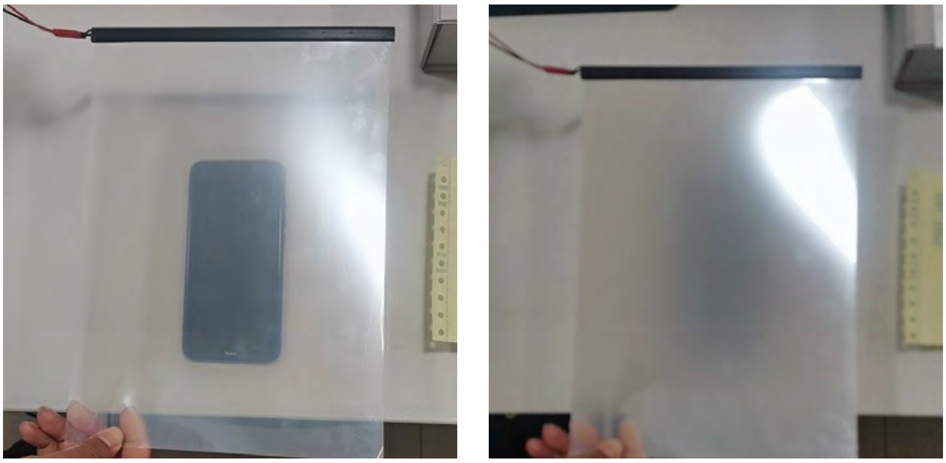

FIGURE 5.6: The PDLC Sample. Left: transparent when powered on. Right: opaque when powered off.

In addition, certain thermochromic materials can effectively indicate temperature changes by changing color when they become hotter or colder. This thermochromic paper, depicted in the Figure 5.7, is composed of multi-layer liquid crystals. Liquid crystals are commonly utilized in precise applications due to their ability to respond accurately to specific temperatures. The paper is designed to exhibit a range of colors between 23 and 33 degrees Celsius, allowing it to reflect variations in body surface temperature. Within this temperature range, it will sequentially display red, orange, green, and blue colors; outside this range, it appears black. This reversible color change occurs as a result of heat conduction principles and also exhibits a slight time delay.

5.4.2 Software Support

In workshops 1 and 2, the interactive application was built using TouchDesigner (Figure 5.8), a software product developed by Derivative. At the same time, the name TouchDesigner also refers to a node-based visual programming language specifically designed for creating real-time interactive multimedia content. This means that when developing applications with TouchDesigner Software, each function is encapsulated within a visual box called a procedural operator. These operators have inputs, outputs, and multiple parameters. Consequently, instead of writing scripts in programming languages like C++ or Python, functions are implemented by selecting operators, defining parameters, and determining their respective order of execution. This creates space for flexibly manipulate visual effects without spending too much time on programming and debugging. Additionally, and very importantly, TouchDesigner has built-in support for Kinect using Microsoft's official Kinect for Windows SDK. All these features make it an efficient tool for supporting our design action.

To create stunning audio-visual performances in our interaction, another software focused on digital audio creation named Ableton Live was also used (Figure 5.9). Ableton

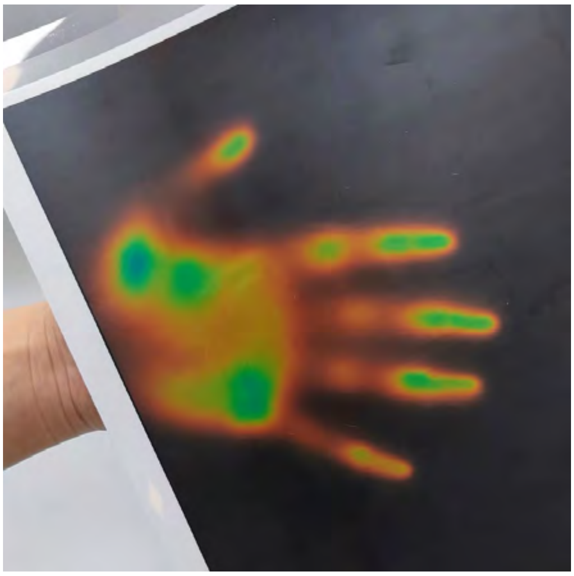

FIGURE 5.7: The thermochromic paper which can present colorful palm

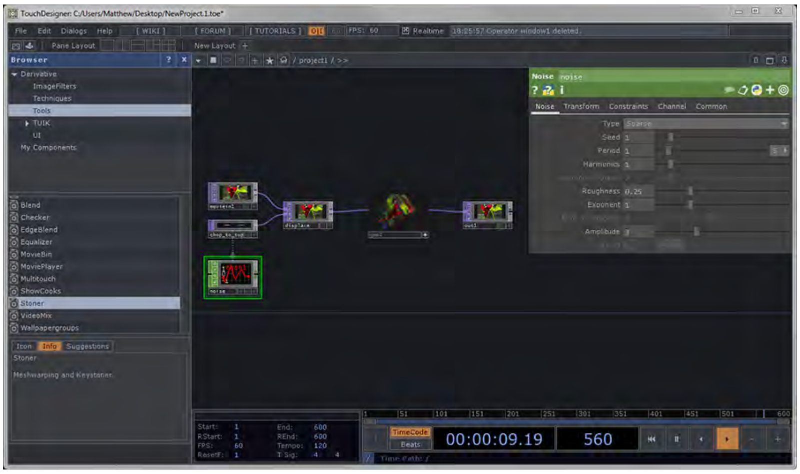

FIGURE 5.8: Window pane of TouchDesigner Software

FIGURE 5.9: Window pane of Ableton Live 10 Software

Live is both a tool for composing, recording, arranging, mixing, and mastering and a go-to application for audio performances. It can play nicely with TouchDesigner. In TouchDesigner, we make use of TDAbleton, a procedural operator or a function, to link TouchDesigner tightly with Ableton Live. This tool offers full access to most of the things going on in an Ableton set, both for viewing and setting. By setting the protocols up between Ableton Live and TouchDesigner, we are able to integrate music or audio elements into our interactive system.

In workshop 3, the open-source Arduino Software (IDE) makes it easy to write code and upload it to the UNO board. Overall the Arduino programming language is similar to C and can be expanded through C++ libraries. It makes controlling complex sensors and actuators possible, especially when one function does not work, there are many support resources for it. For example, to get access to the ultrasonic sensor data, a library named HCSR04 was provided for convenient function calls. However, as I was adding a buzzer for the sound module, the data conflicted with the ultrasonic sensor data (later I understood they both occupy the fundamental sound channel). However, a NewPing library was found to support such a multi-sensor situation. Such rich resources help me avoid much time on rebuilding the wheels and therefore focus on the whole system functions.

Chapter 6

Wall Form: Workshop 1 & 2

6.1 Ideation

6.1.1 Selection of Ideas

The first implemented prototype was from an idea selected from the results of two brainstorming sessions. These two brainstorming sessions were centred around the mirror and time delay concepts as well as visual stimuli. As shown in Figure 6.1, the idea is to place a glass panel vertically on the desktop. This device will be a semi-transparent glass screen with a touch-sensing function. It will create a ripple-like spreading effect on the glass surface when touched. If two people simultaneously touch their fingers or palms from both sides at the same place, it will produce a strong particle storm effect, as if energy is flowing between them.

This idea starts from the concept of looking in the mirror, but it goes beyond the notion of a mirror and is triggered by the perspective of interactive communication between two individuals. It attempts to define a space that restricts interaction between two people rather than just one. The participants seem to exist in two different worlds, one inside and one outside the mirror. The system encourages each other to imitate each other's movements through feedback.

On the basis of the ideation phase, a series of small questions were raised around the concept of a transparent partition. Is a wall an effective form of dyadic interaction? Does the physical space divided by walls further distance relationships that are already difficult to establish? How do people respond to each other when physical barriers limit

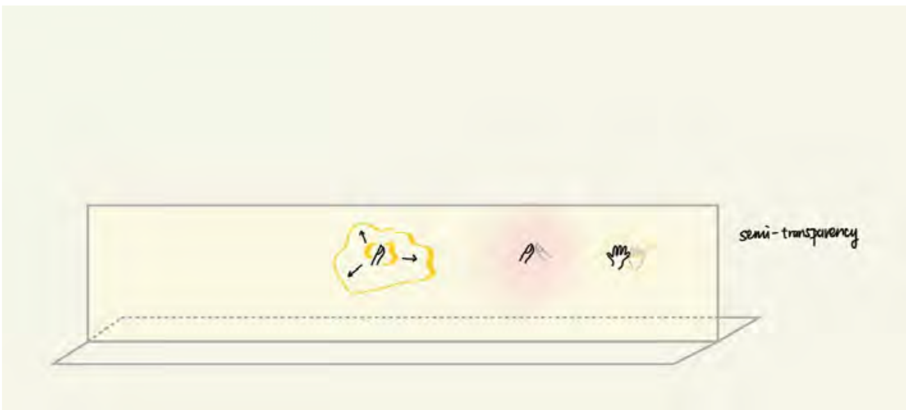

FIGURE 6.1: Semi-transparent glass partition with the touch-sensitive response

their vision? What actions do they take and what emotions do they experience? In order to answer these questions, a mini-workshop was organised with a low-fi prototype to investigate participants' reactions and feelings.

6.1.2 Idea Validation

As shown in Figure 6.2, two transparent glass walls are vertical to each other. One is named "DoubleGlass", which is covered fully with Post-it notes on both sides. This means there are two layers of Post-it notes, and only when both sides have been peeled off at the same position can you see through them. Most of the Post-it notes are the same yellow colour, but there are six locations using orange Post-it notes on both sides. It is intended to test people's reactions to differences in colour. The other glass wall, which is named "SingleGlass", is covered partly with Post-it notes on both sides. It ensures only a single layer of Post-it notes when the entire glass is covered. This means anyone can see each other when they tear off a post-it note. Additionally, a camera that can observe the reactions on both sides was set.

FIGURE 6.2: Two transparent glass walls covered with Post-it notes

Process and Observation

The whole workshop has two sessions, each focusing on one wall, with the same procedures. In the beginning, two participants (TA and TB) were invited to stand on opposite sides of the DoubleGlass wall and were asked to tear off the Post-it notes freely. The researcher narrates the instructions first and then doing the recording silently on the site. The instruction is, "Now you can manipulate these Post-it notes freely. You can take off any post-it notes, peel them off or put them on. Try your best to unleash your creativity and vitality." After the first session finished, they were invited to the SingleGlass wall which has the same procedure. After both sessions were finished, a post-workshop semi-structured interview was conducted immediately. The interview was recorded and transcribed with the consent of the participants and the transcripts were coded manually.

The first session with DoubleGlass lasted 6 minutes, and the second one with SingleGlass lasted 3 minutes. During the first session, there were three times simultaneous giggling or smiling in total. When seeing each other through the glass for the first time, both participants burst into laughter. Then, the second time, participant TA led giggling, caused by participant TB approaching the glass wall, pressing the face against the glass and observing through a small hole. They stared at each other while giggling for about two seconds. At this time, the movements in the hands of both sides completely stopped. After 2 seconds, both sides shifted their vision and continued to operate in their hands, with obvious expressions of smiling on their faces for about 20 seconds. There was no obvious front and back movement between the two sides.

Results and Insights

Drawing from the observations and feedback gathered during this workshop, what worked effectively and what challenges surfaced during the experiment were explored. First, the participants both gave positive comments on this workshop. One of the key positive aspects of the interaction was that participants exhibited curiosity towards the other side. For example, when one participant was observing through a small hole created by peeling off the sticky notes, both of them stared at each other and giggled. This is a promising sign, as curiosity often leads to engagement and learning. Additionally, the mutual attentiveness demonstrated through eye contact interactions suggests that the participants were interested in the experience and each other.

Combined with observation and interview results, it's clear that Participant TA was more obsessed with creating by herself, and she would not take the initiative to interact with the other person. She said, "The post-it notes were so good-looking, so I started creating by myself. Actually, I tried to make a pattern, a plane-shaped figure." On the contrary, participant TB had no interest in creation at all but was focused on the changes caused by Participant TA and tried to attract the attention of Participant TA. He repeatedly tried to lift the post-it notes and bring his face closer and kept looking for the area in the double-sided glass where he could directly see the other person (that is, the position where the other person had torn off the post-it notes). "But peeking at the other side (I) can't see much, and then my interest gradually disappears," he said in the afterwards interview.

The observation that participants had a very short engagement time in the mini workshop and became bored quickly is a clear indicator of potential issues. It was due to various factors. Firstly, the activity of using sticky notes itself is very simple and monotonous. Secondly, the act of seeing through the glass itself does not provide any additional rewards or feedback, which limits the stimulation or enjoyment it can bring. There were no perception and action loops that could be sustained. Finally, the cramped space and small size of the glass also limit the participants' physical movements, further constraining their ability to manoeuvre. What's more, confusion arising from unstructured guidance is a common problem in various settings, and it appears to have affected the participants in this context. They were hesitant when they were instructed to play freely and said in the later interviews that they felt confused at the beginning phase.

6.2 Theory: Objective of 1st Iteration System

Now, it is clear that the first issue we must deal with is not to build a human-to-human relationship directly but to engage the participants in the human-to-system interaction. From the mini workshop validation, the wall form itself is not a big barrier. On the contrary, it created mystery and aroused some curiosity at the beginning of the activity. However, the activity lacks elements that sustain interest or it needs to be more dynamic to keep participants engaged over a longer period. Sustainable participants' engagement in the system activity is fundamental to any further human-to-human interactions with an embedded system. Without a sustained interest in the activity, the system can not play a role at all, let alone facilitate dyadic interaction between participants. Look closely; the low-fi prototype lacked both clear rules for playing together and immediate, spontaneous reactions that attract people to interact with it. This reduced the chances people got stimulated and continued because, from an enactive view, there was no fuel for the sensorimotor coupling to maintain.

What is the "fuel" that can promote engagement and maintain interest? According to the Goldilocks rule, maximum motivation occurs when a human faces a challenge of just manageable difficulty, which are tasks that are right on the edge of their current abilities [18]. Once we learn what to expect, our interests start to fade. It is further found in modern gambling systems that to avoid such boredom, we need to give variable rewards – the pace of rewards varies, which can lead to the greatest spike of dopamine. The sweet spot of human desire occurs at a 50/50 split between success and failure: enough winning to experience satisfaction and enough wanting to experience the desire. This mechanism is also widely used in game designs. Therefore, it is identified that the "fuel" can be either a game rule or a consistent feedback system that balances the participants' satisfaction and expectations.

However, the pursuit of individual engagement in the system can conflict with the ultimate goal of helping build social connections. If the participants can not enjoy the system, the game is over and there are no further chances for deeper bonds. In contrast, if we make the participants too addicted to the system, then it is also dangerous that they may completely lose interest in other participants. How can a complex human being be more attractive than a dedicated, designed, pure game? No one wants to be put into such competition. Even when considering the mechanism for sensorimotor coupling, we can never ignore social situatedness. A variable rewards mechanism can be a tool to attract the participants, but at the same time, it can not and should not become the main character of the whole system. Therefore, this stage's objective is to get the participants engaged in the human-to-system interaction but reserve space for curiosity towards other participants.

Two hypotheses were suggested based on such reflection. First, if we find an appropriate mechanism that generates instant feedback, participants will be interested in approaching the device. Second, if the system creates certain changes over time, they will maintain the interest for more time.

6.3 Initial Design: 1st Iteration of Nudgo System

6.3.1 Concept Development

The initial version of the system design was the continuation of initial ideas with more details. Overall, it was designed that this system is composed of a semi-transparent curtain wall as output. Movement sensor and detector for hand and material contact are served as input. The visual effect can be seen on both sides of the curtain wall.

There are three modes in this design. The first mode is triggered when the system detects someone approaching, and a light spot appears, as shown in yellow in Figure 6.3, the size of the light spot changes according to the relative position between the person and the wall. The spot becomes larger when the person approaches and smaller when he moves away. It follows the person's left or right movements and shows a breathing light effect when he/she keeps stationary. The second mode generates two light spots to simulate hand movements, which encourages participants to use their arms more. The third mode is triggered only when there are participants on both sides of the wall. A palm-sized cursor appears on the wall, which adjusts its size according to the proximity of participants, stimulating their curiosity to place their palms on the wall. When a participant touches the wall, feedback is given through light waves like ripples spreading outwards from that touching point. If participants from both sides approach with their palms touching, they can see each other through transparent walls; however, if either side retreats, the walls become opaque again, and the palm-sized cursor will appear somewhere else on the wall.

6.3.2 Design Positioning and Requirements

Design sketch, as shown in 6.3, is a complete representation of an ideal interaction scenario. It includes not only the individual process of understanding but also the triggers for collaborative understanding - the means to encourage participants to engage with each other's sensory and motor experiences. However, this goes beyond our current needs and violates the principles of participatory meaning construction. It presents a specific path, representing the designer's expectations for constructing meaning, but it limits flexibility in human involvement. For instance, the requirement of mutual touching offers only one option – to touch. In reality, it would have very little chance of happening with such loose guidance and participants can easily get bored. Additionally, the actual implementation will be influenced by hardware and software resources, as well as the designer's skills, which will be further discussed in the implementation section.

Nevertheless, it does partially reflect the needs of my hypothesis. Certain factors have been identified and confirmed: firstly, there is still a physical wall separating the entire space from the participants; however, this wall allows for awareness of the other side and imagination through reserved features rather than being completely opaque. Secondly, visual stimuli remain the primary source of perception. While not perfect for embodiment purposes, the large size of the wall enables full-body movements. Lastly, sharing visual feedback plays a crucial role in amplifying awareness among others and facilitating synchronised movement.

Overall, the purpose of this wall design is to create a buffer zone for both neurodivergent and neurotypical participants. Usually, when they are not familiar with each other, they may feel nervous about potential interaction. Sometimes, they may be irritated or confused by the other person's behaviour. This wall can block part of the line of sight, thus reducing the discomfort caused by excessive or insufficient eye contact. In this way, they do not have to feel overwhelmed or frightened due to direct contact at the beginning. What's more, both parties can reserve certain control over their territory. This provides a transitional state that allows for both progress and retreat. They can have more time to get acquainted with each other and gradually build trust.

6.4 Implementation: 1st Iteration of Nudgo System

Figure 6.4 shows the structure of the physical system, which consists of sensors, computers and actuators. As a way of detecting people's bodies and their movements and gestures, two Microsoft Kinects were used to capture the movements and gestures of the participants on different sides of the wall. Then, they were both connected to the same laptop. A projector connected to the laptop shows the generated visual effects on the projection screen. The use of sound, in turn, is made through the use of speakers embedded in the laptop.

6.4.1 Display Solution

How can a semi-transparent wall be created to display images from both sides? The initial idea was to use LED transparent films on both sides of the glass. However, due to the high cost and difficulty in aligning them perfectly, as well as the strict visual display module control requirements, this idea was not adopted. Instead, a more traditional projection method was used. During material exploration, it was discovered that thinner projection

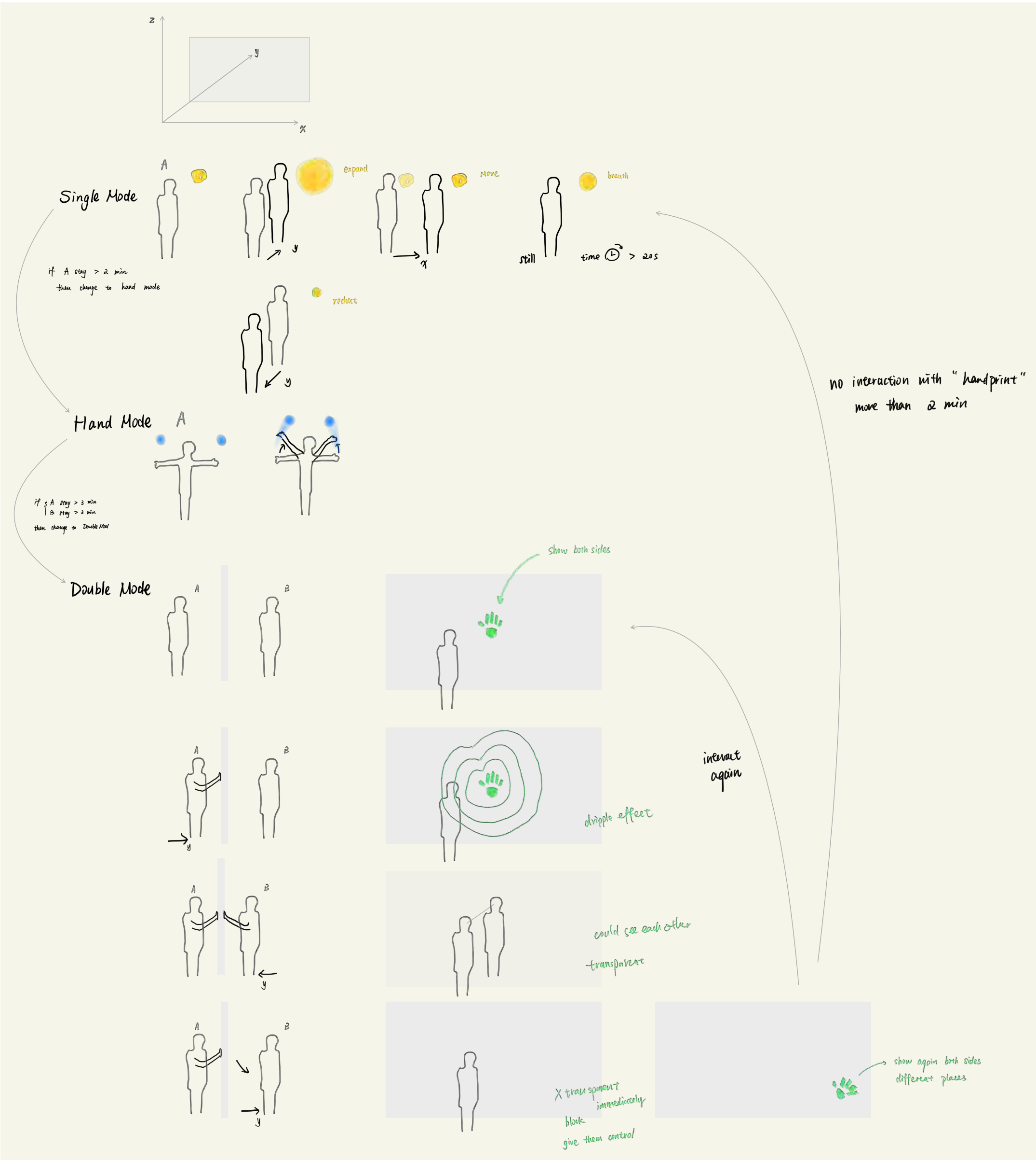

FIGURE 6.3: 1st iteration conceptual system design

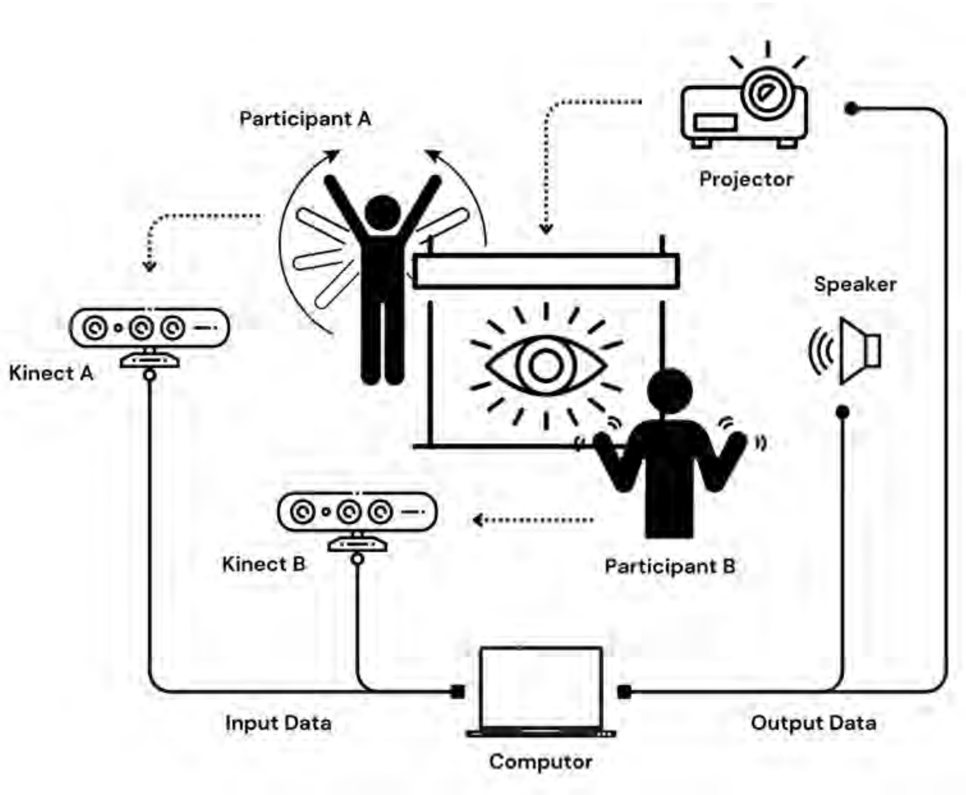

FIGURE 6.4: The structure of the wall form Nudgo system

screens with seemingly poor quality have strong penetration power, allowing images to be seen from both sides. The premise is that the surrounding environment needs to be relatively dark while the projector requires higher brightness for optimal use[1]. Compared to using transparent LED materials, this alternative solution is much cheaper and easier to store and transport but has the disadvantage of potential blockage by participants. As shown in the figure, this projection screen shows the projected image from both sides while allowing participants to perceive the existence of someone on the opposite side.

6.4.2 Software Modules and Functions

There are four modules designed in the feedback loop. As shown in Figure 6.5, the first three modules are independent of each other, and the fourth module functions in the background and works simultaneously with other modules.

The first module is a hand-controlling game with one circle representing one hand (shown in Figure 6.6). After it is activated, there are two pairs of circles shown on the screen, and each pair of circles can be controlled by one participant from one side. So if there is only one participant, he or she can immediately realise that they can only control one pair of circles because the other pair of circles is always frozen in the middle of the screen. But when there are two participants on both sides, it looks more natural, as if the circles are following them.

The second module is the interactive snowflakes (shown in Figure 6.7). It is still based on hand movement. These snowflakes kept spawning and diminishing on the screen. When

[1]Concerning the specific form of the display, the projector used is XGIMI Elfin, whose brightness is 600 ISO Lumens.

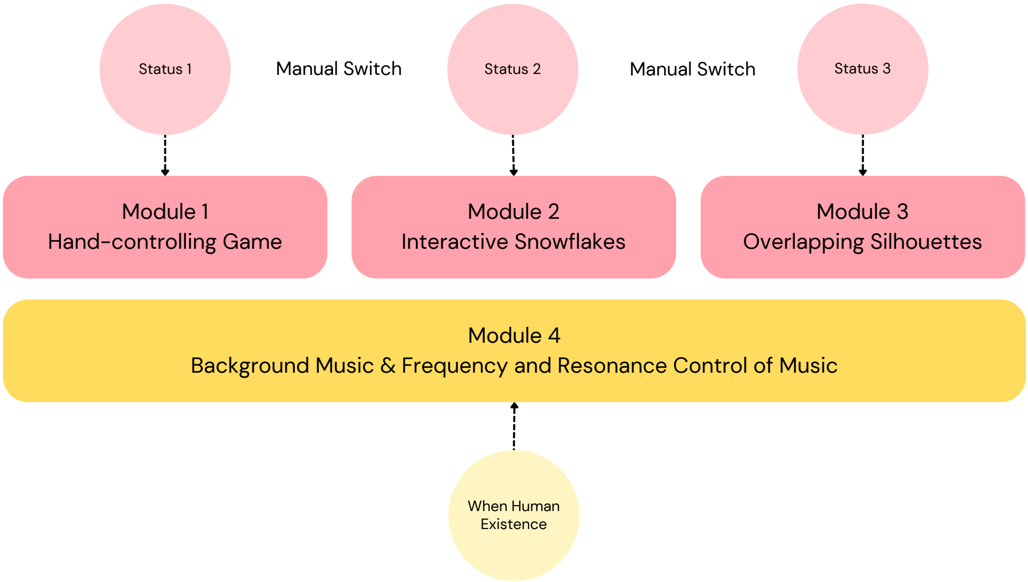

FIGURE 6.5: The structure and function of the four modules

FIGURE 6.6: The visual effect of the first module on the screens for participants. The image on the projection screen is consistent with the computer screen.

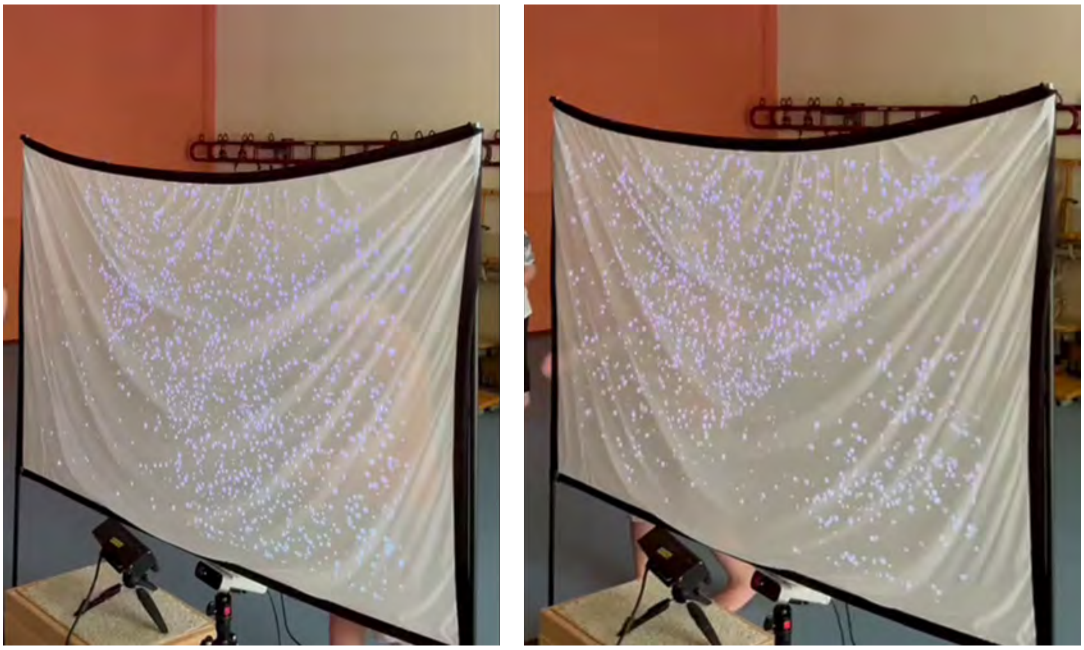

Figure 6.7: The visual effect of the second module on the screens for participants. The sparse areas of snowflakes are where participants approach with their hands.

participants' hands are detected by the Kinect and are within a certain distance (e.g. 0.6m from the Kinect device to the hands), the movements of hands would be converted into forces towards the snowflakes. Then the whole effect looks like we can create some winds by hand to blow those snowflakes. Some factors work together to make simulation feel more natural. First, these snowflakes are created as particles in a simulated 3D space on a per-frame basis. They were given a lifetime on the screen but maintained a certain total amount. Additionally, a combination of initial velocity and random turbulence makes it look more lively and realistic. The detection of hand shapes and transformation is also important. These parameters were calculated as an external force on the particles, which in the appearance of the snowflakes. Compared to the first mode, this mode is more implicit and aesthetic. Similar forms usually appear in exhibitions with embodied interactive experiences.

The third module is overlapping human silhouettes. In this mode, the whole body was shown in a single colour in a solid shape with the outline. This module aims to simulate the experience of individuals observing themselves in a frosted glass mirror. The design allows for two participants standing on opposite sides of the wall to view their own silhouettes as well as that of the other person. As they move and their silhouettes intersect, new colours will emerge on the screen.

The fourth module is controlling the music by hand. This is a module with an activation premise of human existence before the camera. It will loop broadcast a mix of sounds, a simple melody. This is where the software Ableton Live is involved. Here, I prepared two different mixtures: one is a mixture of soft guitar pieces with piano, and the other is a mixture of synth and drum, which is more like a metal style. An auto filter effect which provides classic analog filter emulation was applied to adjust the frequency and resonance of music. These parameters are linked to the coordination of the detected hands of the participants. So participants can control the pitch of the music elements by the height of the hand position. But the change of the music like soft guitar pieces and piano, was not very evident, only the pitch change of music like the metal style, synth and drum can be identified easily.

6.5 Workshop 1

To verify the hypothesis that "If we find an appropriate mechanism that generates instant feedback, participants will be interested in approaching the device", the workshop was mainly designed to observe participants' reactions towards the system design. From a temporal aspect, two stages require close attention. One is how they approach the system and join the game (if it goes smoothly) or fail to join the game. The other is how they quit the game. Furthermore, particular emphasis is placed on the neurodivergent participants to ascertain the following crucial factors: Firstly, did they exhibit any indications of being aware of individuals on the opposing side? Secondly, how do they handle potential discomfort when encountering unfamiliar people on the premises? Lastly, what types of behaviours present opportunities for further design improvements?

6.5.1 Design of the 1st Workshop

The procedure of the workshop is as follows. After the system is installed, there will be two sessions with the same procedure and different pairs of participants. Each pair of participants is a mixneurotype, more specifically, a neurodivergent child and a neurotypical adult. The participants would be introduced into the room first and be guided to different sides of the screen. To better indicate such separation and alleviate confusion, the screen would installed vertically to the wall which has the door. So, after participants enter the room, they can immediately see different sides of the screen and make a choice to enter either side.

In the beginning, the researcher would give instructions to the neurotypical participant while the supervisor teacher would help us guide the neurodivergent children to participate in the game. Since the system would be on before all participants have taken the position, they would naturally get engaged in the first mode. Then, the researcher would shift the modes during the process. When the participants quit, the session ended. Then, there will be a short interview towards the supervisor teacher after all sessions have ended.

6.5.2 1st Workshop Process

Because a lot of devices were involved, they were brought in parts and assembled on-site. The installation of the system took about half an hour. During the software testing, I found that module 3 could not clearly display the silhouettes due to too much image noise, so it was abandoned in this workshop. Once the entire system was set up, the teacher was invited to be the first to interact with it. This allows for early identification of potential risks and helps the teacher gain a better understanding of how to guide the children.

The actual organisation of the workshop happened with another tactile workshop organised beforehand. Purna, a researcher from the same research group, organises this tactile workshop. It was aimed at a final testing of her design, which embedded vibration feedback in toys.

Two children (A and B) were invited into the room, and the tactile workshop began. They played with the toys for a tactile workshop on a table in the corner of the room for about two minutes. Then, they were guided towards the screen by their teacher. With the two children unwilling to separate from each other, the workshop is a deviation from the original intention of two-person interaction; it has become a group game. Based on the principle of adaptability, I confirmed with the teacher that it's best not to separate the two child participants and decided to continue with both of them joining together. They were standing with their teacher T0 on one side of the screen near the projector. The neurotypical participant T1 is on the other side of the screen.

Stage 1: Module 1

I *started the module 1* programme. The neurotypical participant T1 immediately recognised what was happening on the screen and she raised her hands high and swung both arms to control the small circles. On the other side, the children gathered around the teacher, looking at the screen and back at the teacher. While explaining to them this is a dance game, the teacher swings her arms up and down. Under such guidance, two children moved close to the screen and began their engagement.

Then, after about 3 minutes of interaction, I noticed that the teacher and two children were blocking the projection on the screen by standing too close to the projector. So I asked them to *switch the position*: the neurotypical participant would move to where the children were standing, and the teacher and two children would move to where the neurotypical participant originally stood. The children didn't show any discomfort with this arrangement; they followed the teacher and moved to the other side. During this exchange process, child B ran to the corner, picked up two toys that he had played with in a previous testing, and brought them back within range of the screen. Then, both children played for a while but soon showed signs of losing interest: child B started focusing on the toys in his hand, and Child A moved closer to explore what was happening near the researcher's laptop. I decided to *switch to module 2*, the snowflake game.

Stage 2: Module 2

After switching to module 2, *T1 left the game* for personal reasons (unrelated to the game itself), and *I took her place as a participant.* Two children gathered around the teacher again - they both wanted to hold hands with the teacher while they danced. After a while, child B walked away. The teacher then held child B's arms, trying to involve him in the game. The impact of this guidance lasted for one minute, and child B stared at the screen. Then, he did not try more movements.

Stage 3: Module 1 (Second Time)

We *returned to module 1.* Child B stayed briefly and then walked away again. During the rest of the time, child B repeatedly returns to the game and leaves. On the contrary, child A stopped relying on the teacher and enthusiastically engaged in the game. After vigorously waving both arms in front of the screen, child A started spinning and dancing. Then, child A and I interacted a lot, which would be discussed in the analysis. Until the agreed time is over, the children have to leave for class.

In conclusion, three neurotypical adults (including me) and two autistic children participated, and the whole session lasted about 20 minutes. I then did the interview with the teacher. The entire process was recorded on video, and the subsequent analysis is based on the recorded session video and audio interview.

6.5.3 1st Workshop Observation and Analysis

The behavioural tendencies of the two children are consistent with their performance in the inquiry workshop, where child A was more active and child B was more passive towards

FIGURE 6.8: Child A turned around and sought the teacher's hand to dance together, then was guided by the teacher to turn towards the screen.

the new game. Overall, the teacher was surprised and satisfied with the results of the workshop. She said:

> "... They know what to do. It's very nice to move the arms more, stretching more. Usually, they do not have much chance to do that."

Child A was always smiling and laughing during the whole session. He seems to be very attracted by the floating circles and snowflakes on the screen and his arms expand as he jumps up and down. Most of the time, his face was either facing the screen or seeking attention from the teacher. His attention can not last for a long time. After twenty to thirty seconds of facing towards the screen and moving his arms, he usually turns back and hugs his teacher. Then, the teacher would dance with him and gradually lead him back to the interaction. Such a loop of behaviours (Figure 6.8) occurred more than five times in this session.

Child B usually runs to a distant area away from the screen and shows more interest in the folded slides in this room and the plush toys. He also joined the game multiple times proactively and kept touching the soft fabric of the screen by swinging his arms left and right. However, when he faces the screen, most of his movements look more like mimicking the teacher or child A's behaviour. But even though he did not show much favour toward this system, he did not show signs that he was nervous, according to the teacher.

Neurotypical participants of the session put more attention into the children than themselves. During the interview, the neurotypical participant T1 said she kept focusing on what happened across the screen when she was moving her arms. When asked about why she was focusing on the other side, She said:

> "It was interesting that I could see the patterns on the screen and the children on the other side at the same time. I was curious about what they would do."

Additionally, we found out that the Neurotypical participants (T1 and me) both had their knees on the ground when they participated in the session. It was not intentional behaviour, but it came naturally to the participants. This unconscious behaviour has many benefits. It brings participants with significant height differences to the same eye level. It promotes visual communication between both parties and creates an atmosphere that feels more equal.

There are two explainations for such behaviour. The first is the height of the screen. Children's line of sight is aligned with the centre of the screen so they can maintain an upright position and comfortably look at the screen. However, bending over for a long time is not as comfortable for adults, so kneeling or squatting can be more comfortable

FIGURE 6.9: Movement synchronisation between Child A and Adult T1

FIGURE 6.10: Movement synchronisation between Child A,B and Adult T0,T1

to participate in. Second, the sensor is placed below the screen, making it easier for the body to be within the range of the sensor when kneeling. Since the participants can notice the camera, they are intended to adjust according to the camera's position and find a convenient control position. However, children do not typically adjust their body position to align with the camera's position. Instead, they often display indifference towards the sensors.

Acoustic Sensation Preference

Child A was found to have great affection for music. This, to some extent, explained his passion for this game session. "Last time we danced with music, so he linked it with dancing." The teacher explained. As designed, the system would stop playing the music when no person was detected in the camera. There were several times the music stopped due to blocking or empty vision, and Child A would put his arms down. And when the music was back, he danced again.

Furthermore, the music played at the beginning was a mixture of synth and drum, which was very strong. After it began playing, child A laughed and jumped and immediately danced. Child B followed, too. They seemed very excited about it, so the music style remained unchanged in the session. This was unexpected because the music sounded very strong and a bit noisy. It is usually considered too stimulating for children with autism. But they were rather fond of it. This should be a personal circumstance; for example, child A is very sensitive to auditory stimuli and has a strong sense of inclusiveness. Without further validation, it should not be regarded as a collective situation.

Specifically, participants did not recognize the module 4 music control mechanism during the workshop. The neurotypical participants T0 and T1 did not realise that the frequency of the music was related to the height of their hands. At the same time, the children were found to be only sensitive to the presence or absence of music.

Awareness and Coordination

There was a clear indication that the children were aware of what happened on the other side of the screen. For instance, child A occasionally walks to the edge of the screen and peeks to see what the other participant, T1 or I, is doing on the other side, showing a similar level of curiosity as when he peeks at the computer. In the interview with the teacher after the session, she said:

> "(Such awareness) depends on the children. It took some time for them to understand the whole system. Sometimes he (Child B) needs more repeating to recognise that."

A lot of movement synchronisation was found during the session. Most of them were led by neurotypical participants. For instance, when I began moving left and right and crossed my arms, child B adopted this way to move the arm horizontally as well across the screen. And when I shifted from big arm movements to shaking my hands slightly and quickly, child A followed, too. T1 often waves her arms up and down, and child A also imitates this action of waving her arms up and down (Figure 6.9). Their movements show a certain rhythm. However, Child A's rhythm is slightly delayed compared to T1's movements. More frequent is the coordination of actions between children and the teacher T0. Often, at this time, T0 acts as an intermediary to mirror the actions of the child and either T1 or me. Therefore, we can observe all participants making the same movements (Figure 6.10).

Person-to-person Interaction

The unexpected behaviour of child A in the middle of the session validated the assumption that children maintain awareness of what happened across the screen. While spinning in circles, he moved from one side to the other side of the screen. As a result, he stood on the same side of the screen as me and made a downward crossing motion with his hands towards the screen[2]. In his attempts, the circles on the screen responded to his movements as he continuously twisted and distorted his arms. At the same time, he turned around with both hands clasped together and made a searching gesture towards me behind him (Figure 6.11). I immediately responded by leaning in and unconsciously imitating his action of putting fists together and gently opening my palms and shaking them up and down. The circles on the screens move following my movements. He was curious about what was happening on the screen, and he was observing the screen repeatedly from both sides by walking around twice. Then, he returned to my side while performing actions and observing how I controlled the screen for imitation. I was kneeling behind him at that time, and he would occasionally turn his head to observe my hands, then make similar movements towards the screen. Later, when I stand behind him. I reached out my hand to him proactively, and he glanced at my hand and then made various gestures towards the screen.

6.5.4 Insights for Next Design Iteration

Overall, the first workshop verified that displaying users' actions on the screen can have a stimulating effect on curiosity. However, this way of continuously providing feedback in

[2]At the beginning, the sensors had difficulty capturing his hand movements because he was too close to the screen. He tried several different actions repeatedly. At the same time, my attention shifted from the screen to him, ready to teach him how to control it. At the same time, the teacher was standing back near the wall observing his behaviours.

FIGURE 6.11: Interaction between child A and the researcher. First row: Child A observes and mimics the researcher's movements. Second row: The researcher proactively attempts to teach child A.

a simple form lacks sustained appeal. I need to re-engage participants' attention through manual mode switching. A more immediate and obvious feedback loop is needed. For example, certain forms, such as buttons, can be "addictive" to children because of the joint effect of pressure sensation, sound, and changes in a visual environment. During the inquiry workshop, child D showed great interest in the light switch after entering the room, repeatedly turning it on and off several times. What's more, the structure provided only by the space separation is not enough. A period target should be provided. Goals bring people action frameworks, directions, focus, and purposes. It would be ideal for them to share a common goal achievable through action. These reflections promoted design improvements for the next workshop.

6.6 Design and Implementation: 2nd Iteration of Nudgo System

Workshop 2 was arranged one week after the workshop 1. The hardware system structure remained the same as in Workshop 1. There was only one module, which was a variant of the first design. The internal logic is completely different.

6.6.1 Software Design and Function

In the 2nd iteration, there are two solid small balls on the screen. One is yellow and the other is blue. They are separately controlled by participants on each side of the screen and can only be controlled by the right hand. Four rotating cubes are added to the screen. Each cube represents a sound. When the ball representing the participant's hand hits a cube, the cube changes colour and triggers a sound, like drumming or pressing a key on a piano (Figure 6.12). If the participant simultaneously touches two different cubes, a lightning-like line will be generated between the two cubes as a reward. It is also implemented so that the small circles are expanded when the participants get closer to the screen and shrink, and vice versa.

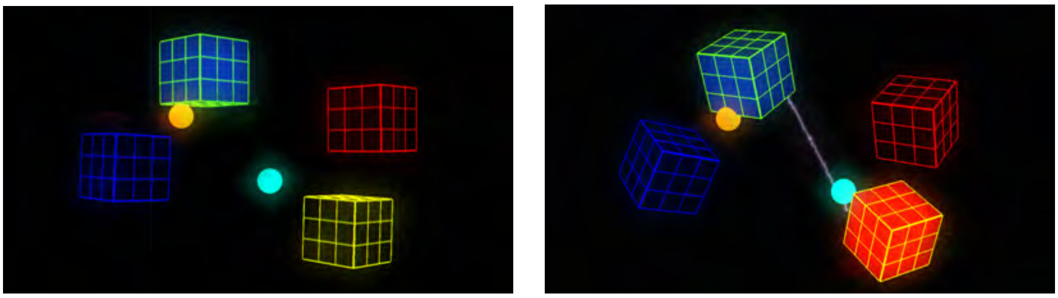

FIGURE 6.12: Left: Effect when one cube hits the ball. Right: Effect when two cubes hit the two balls.

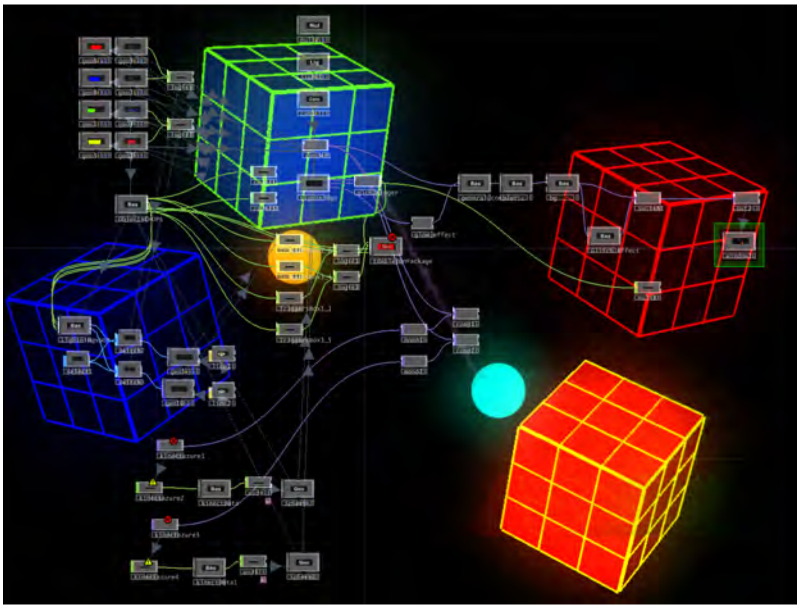

FIGURE 6.13: The structure of the 2nd iteration programming

This version of the design aims to create an interactive instrument. Compared to the first version, the rewards will be more obvious and explicit. Because module 1 in the first version was played the most during the workshop session, in this version, I reserved the characteristic of using a hand to control the circles - the simple mapping relationship between hands and graphics on the screen. However, since some cubes are added in this version, the screen becomes richer and more crowded. The mapping of two hands was cut to only one hand. This can reduce the level of confusion and minimise repeated accidental touches. Then, shifting hands can cause the circles to jump on the screen, so it is ruled that only the right hand, the dominant hand, can control the circles.

6.6.2 Programming and Implementation

The beginning phase is similar to module 1 in the first version. We first got access to the Kinect Azure data and the right hand is detected and focused (Figure 6.13). Then the raw data is transformed into (x, y, z) coordinations in a virtual 3D space to create the solid balls as well as a (u,v) coordination to locate the hands in the screen plane[3]. The size of the radius of these balls is determined by the hand's z-coordinate (z represents the

[3] The u and v values goes 0 to 1 left to right and bottom to top.

distance between the hand and the screen)[4]. Then, in the rendering space, four cubes are created and rendered. Here, I let them rotate at a certain speed and at different angles to enhance the aesthetic sense and give them different colours.

An algorithm called Render Pick is used to detect the collision of the hand-controlled circles and the cubes. Render Pick can return the 3D information from the geometry at that particular pick location and inform the picked status. Therefore, with the (u,v) coordination of the hands as input, it can determine whether a cube has been found at the search location.

Next, I tried to connect the picked status of each cube with its colour, brightness, and corresponding sound effects. The implementation of this phase is based on TouchDesigner and Ableton Live, which is similar to the implementation of module 4. If a cube is picked, it will become a brighter full colour and create a sound. Different from module 4, this sound is short and does not loop. The two cubes on the left and right represent drum sounds with different tones, while the two cubes on the top and bottom represent piano key sounds. They can be clearly distinguished from each other, but when played together, they are also very harmonious.

6.7 Workshop 2

In Workshop 2, I want to repeat the same procedure as Workshop 1. However, considering the confusion caused by having both children participate together in Workshop 1, I strictly limit the number of participants for each session this time. Only one child and one neurotypical adult are allowed at a time. Two sessions were organised overall with child B, child C and me. It is still the same teacher who serves as supervisor and facilitator.

6.7.1 2nd Workshop Process

In this workshop, the preparation time for the equipment is relatively long. However, the teacher brought Child C in before I had finished setting up the equipment. As a result, the teacher had to play some other games with Child C first to attract her attention.

Session 1

Then, when everything was prepared, all participants came in. Child C went directly to the screen and was attracted by the cubes. I went to the other side of the screen and waved my right arm. Child C follows the balls with her head on the opposite side of the screen. After several attempts, she lost interest (the balls did not react to her head's movements) and began to look around the venue. The laptop attracted her, but she soon was taken away by the teacher. The teacher guides her back to the screen. After pausing for a few seconds, she walked away and settled on the stool in the corner.

The teacher asked her back to screen she did not refuse. But when she was in front of the screen, she curled up both arms in front of her chest and repeated a sentence four to five times. The teacher came to her and tried to comfort her. But she stood on the stool and kept repeating the sentence (Figure 6.14). The teacher tried to lead her back to the game. But the girl doesn't want to participate any more. She just sat there and stared at the outside. The teacher said she was angry because she found out that I could control the balls but she could not. After confirming that she would not participate any more, I went to the backup plan.

[4] r=0.1-0.001*z

FIGURE 6.14: Child C kept repeating the sentences alone and refused to participate

FIGURE 6.15: Child B was playing the thermochromic paper with the researcher

I left the screen and showed the thermochromic paper on the table. First, I leaned in and pressed my hands on the paper. This action caught her attention. She came to the table and put her hands near my hands on the paper. After a few seconds of pressing, I released my hands and the girl released her hands too. We watched the patterns gradually disappear on the paper and repress our hands on the paper together. She was attracted by the magic visual effect of the material. We repeated the whole process three to four times, and she gradually calmed down.

Session 2

After a short break from the first session, child B was introduced into the room. The teacher tried to hold his hands to teach him how to play. However, child B was letting the teacher guide him passively instead of actively using his own body. After a moment, he broke free from the teacher's embrace, walked forward on his own, and used his hands to scrape back and forth on the curtain. Then he was back to stick by the teacher again.

It was clear that he was not interested because he always looked elsewhere instead of staring at the screen. Due to the experience of the first session, we did not let this situation continue for too long and shifted to the table near the screen. Here, thermochromic paper was provided again. After initially placing his hand on the paper with some doubt, he quickly engaged in interaction with me (Figure 6.15). At first, I kept my hand on the material for a long time without moving, while he constantly flipped it open to look at it. But soon he also placed his hand on it and didn't move. When I removed my hand, he did, too, and we saw our own handprints left on the material. Then he placed both hands on the material, and I did the same. After that, I tried touching the paper surface with my elbow, and he twisted his arm to do so as well, occasionally looking at me.

6.7.2 2nd Workshop Observation and Analysis

Overall, workshop 2 did not go smoothly, and the participants showed a certain degree of indifference or alienation. This is closely related to the failure of system operation. Firstly, the system's gesture recognition is not sensitive, unlike the camera's low tolerance demonstrated in the first workshop. In the first workshop, being too close to the screen will obstruct the camera. participants need to keep a certain distance (about 0.5m) from the screen to achieve optimal control effects. In the second workshop, hand recognition is very unstable; for example, when hands are swung vigorously, the ball often just shakes in place. Sometimes, teachers can control it with their hands while children standing together cannot. It was later discovered in research that Azure Kinect does not provide a stable output value immediately after being turned on [83]. It requires a relatively long warm-up time (at least 40-50 minutes) for the output to stabilize. However, Workshop 2 was organized right after installation, which explains the low precision of hand recognition during the workshop.

Secondly, the system's volume was too low. Therefore, the original design purpose was not reflected; participants can only see colour changes in squares but cannot hear corresponding drum sounds. Instead of silence, The system has a weak sound that needs careful discernment. However, this stimulation is too weak for children [5]. The sound could not be recorded by cameras placed far away.

However, the backup thermochromic paper works very well. Due to the colourfulness, it is attractive enough for children to get engaged. Because participants need to wait for a few seconds to let it show colour, it creates a possibility for all participants to stay together and get close. This also cultivates patience and endurance. At the same time, different body parts have different temperatures. This creates space for more experimental tries and mirroring behaviours. For instance, the boy in the second session and I mirrored each other to explore more different patterns. Furthermore, participants can compare each other's patterns due to the difference in body temperature. This can enhance the embodiment experience.

6.8 Theory: Reflection of Wall Form Nudgo Systems

6.8.1 Participatory Sense-making Analysis

The design intention was a participatory sensemaking process that gradually transitioned from individual-orientated sensemaking to joint sensemaking with the increase of time. In Workshop 1, the main driving force behind this transformation is the manual control of module switches by designers. There were two module switches throughout the session. The first switch was from module 1 to module 2 when I observed that all participants, including both autistic and neurotypical children, became distracted from the screen. This

[5] I discovered this problem when setting up and debugging. But even turning up the computer volume to maximum did not solve it. This has never happened before during the implementing and experimenting stage.

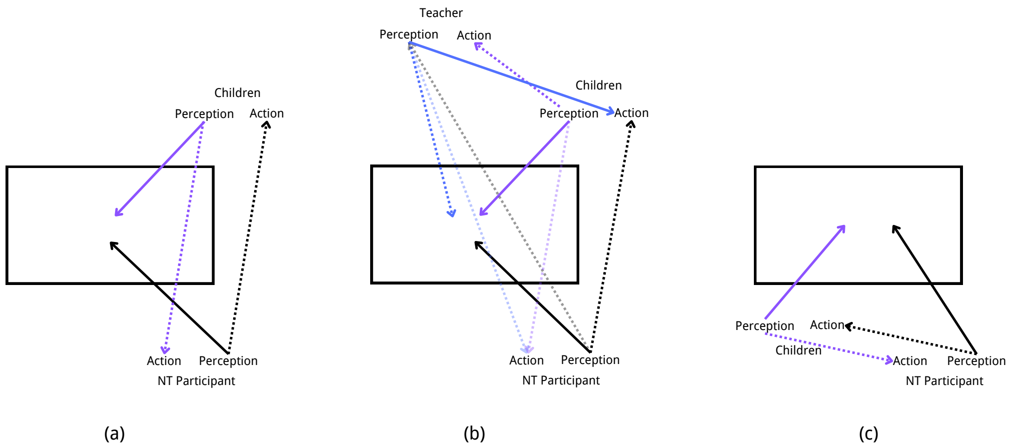

FIGURE 6.16: Analysis of participants' attention: Arrows indicate the direction from the perceiver to the perceived object. The solid line represents heightened attention, while the dashed line indicates relatively lower attention. (a) The designed and expected mutual attentiveness; (b) The actual group perception distribution; (c) The mutual attentiveness happened when the teacher standing from a distance.

decision proved effective as it introduced a new exploration stage - with the teacher pointing towards the screen, the children's focus returned. The second switch occurred when I noticed that the teacher was holding child B's arms in an attempt to involve him, causing child A to also lose focus. It was discovered that children reacted more enthusiastically while playing with Module 1 compared to Module 2. In retrospect, these switches maintained participants' interest, so the transformation from individual-orientated sensemaking to joint sensemaking became possible.

How did the transformation from individual-orientated sensemaking to joint sensemaking happen? The system was designed to make use of the autonomy of interaction to influence the participants in an unconscious way. Specifically speaking, in both workshops, when participants were controlling the balls on the screen, their movements usually looked like they were mirroring each other. That is, without requiring the interactors to do so, they were doing the synchronisation and observing the other person doing the synchronised movements at the same time (see Figure 6.16 (a)). The mappings on the screen serve as an additional layer of perception-action indicators. It's a game of "fake it until you make it". In simpler terms, even if both sides don't intentionally copy each other, due to the limited range of ball control movements, there is a strong likelihood that they will develop similar movements and rhythms. It is the trick of the design to relieve or solve the sensorimotor differences between autistic and neurotypical participants, especially the rhythm capacity difference. Since the history of interactive engagements will influence embodiment and sense-making, such an adjusted and harmonious coordination can provide a positive foundation for further contact.

However, the actual situation was much more complicated due to the participation of the teacher (see Figure 6.16 (b)). In Workshop 1, it was observed that children's main imitating target is still their teacher. The teacher usually mediates the high movement similarity between the neurotypical participants and the autistic children. According to the analysis of the line of sight, the teacher was mirroring the neurotypical participants' movements unconsciously, and the children were following the teacher. At the same time, the neurotypical participants were watching the children and doing some similar movements without consciousness as well. It became a multi-party participatory and multi-point attention interaction. This makes coordination and the mutual attention between autistic children and neurotypical participants uncertain. The teacher partly substituted the role of the system.

The truly clear and obvious participatory sensemaking occurred when Child A in Workshop 1 came to my side and made actions imitating my behaviour (see Figure 6.16 (c)). As shown in Figure 6.11, it was clear there was a mutual attentiveness between us and a common focus on the screen patterns. Like the unexpected behaviour of child C in the inquiry workshop where she sat together with the researcher, these behaviours bring feelings of connection. However, why do the phenomena of the girl sitting with the researcher and the boy attempting to learn behaviours arouse our interest? Our subjective impression is not groundless. As neurotypical people, we were looking for certain signs that we were not treated like objects but as human beings. If we evaluate the three elements of rapport-mutual attentiveness, positivity, and coordination- we find that such phenomena or mutual behaviour satisfy these elements.

6.8.2 Conflicts in Wall Form Design

Two main conflicts were identified in the workshops. First, the mutual control of the circles or snowflakes seemed too complicated for autistic children and too dull for neurotypical adults. It took the children about ten minutes to understand the mapping relationship and the neurotypical adults could recognise it in ten seconds. Second, though the wall form was designed to create a safe buffer zone between participants, what brought true interaction occurred when participants were on the same side or at a very close distance.

Commonality difficulties

The conflict of the complex level reflects the shortcomings of selecting representative commonality features. The advantage of fully mobilising limb movement and stretching arms was confirmed. However, the mapping from hands to patterns on the screen was not successful. First and most important, the expectations of children and adults in this interaction are different. Neurotypical adults find it easier to experience the enjoyment of beauty when there is a certain level of complexity and harmonious patterns. Most people find visual feedback that is monotonous and lacks variation unappealing.

However, complex elements and logical relationships are unsuitable for children's cognitive level. On the one hand, children expect highly responsive items. Insufficient response or lack of control is unforgivable for them. On the other hand, the imbalance of power in participating in games can lead to frustration. When other participants can control the ball but find themselves cannot, the unfairness will intensify their anxiety and anger.

The balance between safety and fun

Though the screen wall serves as a buffer zone for participants, the ultimate goal is still to facilitate each other to interact and develop rapport. Generally, the function of the buffer zone worked well. All participants were calm and comfortable except in the case of session

1 in Workshop 2. Even in such cases, the anxiety and anger were not pointing towards the other participants but the feeling of being deprived of control. However, it was found that children are not as resistant or afraid of interacting with neurotypical adult participants at close range. In the workshop session, neurotypical adult participants also showed interest in continuing to play with the children. With such experience gained from the workshops, the focus of this design should shift to increasing opportunities for contact and promoting stronger communication between each other, a way that can more directly break down the sense of distance between participants.

6.8.3 Insights for Further Design

In Workshops 1 and 2, two important factors drove new brainstorming of alternative possibilities: the distance between participants and the role of the teacher. These two elements become the main driving factors for the next design iteration. In general, in the next iteration, the system design should meet the following two requirements: first, to minimise the distance between users while maintaining comfort for both parties; second, to reduce teacher interference with participating users or provide teachers with a reasonable position for involvement. Additionally, the learning behaviour of non-autistic children from neurotypical adults is considered a better way to solve the commonality conflict mentioned in and can be taken into account in future designs.

The distance between participants and the role of teachers

It was found that all the interactions that fostered connection happened when participants were physically close to each other (within 0.5m). Such closeness was not intentionally designed but happened naturally serving the purposes of real-time interaction. Rather than the Workshop 1 imitation behaviours, there was also some indication of intimacy during the backup stage in Workshop 2 when participants played the thermochromic paper together. Behaviours like sharing space and toys together can be mutually shared in silence. Without effective verbal expression, this body language can achieve a certain degree of self-disclosure. (As discussed in Chapter 1, self-disclosure is an essential element to build intimacy. The other element is partner responsiveness.) Furthermore, when the participants appreciated and compared the patterns they had created together, they enhanced the sharing. This leads them to become relaxed and comfortable, creating chances for further responsiveness. The finding that intimacy is closely linked to distance led to new insights that we should create an opportunity for users to share intimate space.

The role of the teacher is a bit complicated. The system created an open space for participants to engage when they were within a certain radius of the screen. It led to much autonomy for the teacher. On the one hand, we need the teacher's help to create a more relaxed atmosphere and environment and intervene when necessary, such as when the child feels uncomfortable or uneasy. On the other hand, the teacher became a main participant who competed for the child's attention with other neurotypical participants. Therefore, it is not surprising when we discover that all major dyadic connections occur when the teacher stands farther back.

Furthermore, the teacher had a strong expectation of what children should do during the workshop. Sometimes, she guided the children by holding their hands and waving together. This can hardly work effectively. If the system attracted the child, he or she would participate naturally. If the system can not ignite or maintain their interest, such enforcement can only make them more resistant. It was evident in Workshop 2 that the teacher's attempt to attract the children failed.

Rejection of predefined cognition process and new opportunity

The second iteration of the system design was affected by the urgency of attracting and impressing the participants. To provide more direct and clear feedback, both competition and collaboration game mechanisms were considered. For example, competition among participants from both sides will inevitably lead to a significant increase in engagement. Additionally, displaying a timing clock can enhance the sense of urgency and further excite the participants. Such a competition mechanism ensures a high level of coordination and mutual attentiveness. However, it is not always positive. A collaboration game is another form that seems better. In such a mechanism, participants work together to build something, and then they get rewards for their collaboration. It was manifested in the lightning-like line reward in the 2nd iteration of the design. However, this consideration deviates from the original intention of embodied and enactive theory. The logical reward was emphasised. Accordingly, the cognition process was predefined by the designer. They are fatal to the principle of respecting participants' own sensorimotor coupling process since the purpose of the action is given and limited.

On the contrary, children's imitation behaviour in both workshops indicated that suitable activity could arouse curiosity and facilitate the motivation of learning. In the process of exploring a universal communication method, it should not only pursue completely consistent behaviour but also create opportunities for one party to learn from the other and ensure a sense of control for both parties. Learning behaviour is rooted in children. In the process of learning observation, both parties pay good attention and spontaneously generate coordination.

Chapter 7

Tunnel Form: Workshop 3

7.1 Ideation and Design

In the beginning, I wanted to make the wall more attractive in appearance and more variable in form. I was not satisfied with the screen because it lacks certain tangibility and is overall clumsy. For example, the screens can be a series of fragments that are embedded and connected together. Each fragment can be controlled independently to rotate and adjust the transparency. Such variability was considered to provide complexity or freshness with the repetition of simple mechanisms. However, the workshop requires a quick and easily implemented prototype to be tested immediately. Massive repetition is not realistic in implementation. The novelty of a single item becomes very important.

In the experiment on paper, I discovered a new form of creating space which satisfies the new requirement of "to minimise the distance between users while maintaining comfort for both parties" (Section 6.8.3). A vertical plane can be a barrier, while a curved plane creates a new space between the two ends. This space is separated from the external space, forming a strong sense of privacy. It reminds people of how children enjoy listening to stories inside tents because it feels both exciting and safe. However, different from tents, it's best for this space not to be too large, as being completely immersed in it would inevitably restrict participants' freedom. This would result in a deprivation of control and easily lead to anxiety and unease when users are not so familiar with each other. Therefore, naturally, one would think about allowing a part of the body to enter and exit freely.

The tunnel form of this design has been fixed. The next step is the selection of materials that separate the interior and exterior. Choosing transparent materials can enhance visual feedback, while completely blocking the line of sight can increase a sense of mystery. At the same time, the specific materials used in the design cannot be ignored. The smart film found during the initial exploration phase is applied to this design because its characteristic of becoming transparent when electrified is undoubtedly attractive. Additionally, the material samples' size (A4) also narrowed our design choices to a space which only allowed the hands to move in.

What is retained from the wall form of design is the symmetrical attribute that provides a balanced and equal experience. The whole tunnel is symmetrical about the central axis. This means that no matter which end one enters from, he/she will have the same experience. Participants from two sides will meet in the middle or break through the central axis to reach each other's area. Making the experience in the middle natural and smooth is crucial. I hope that in this enclosed space, there can be opportunities for both parties to touch each other. In addition to a sense of intimacy brought by proximity, direct skin contact can further strengthen acceptance of each other.

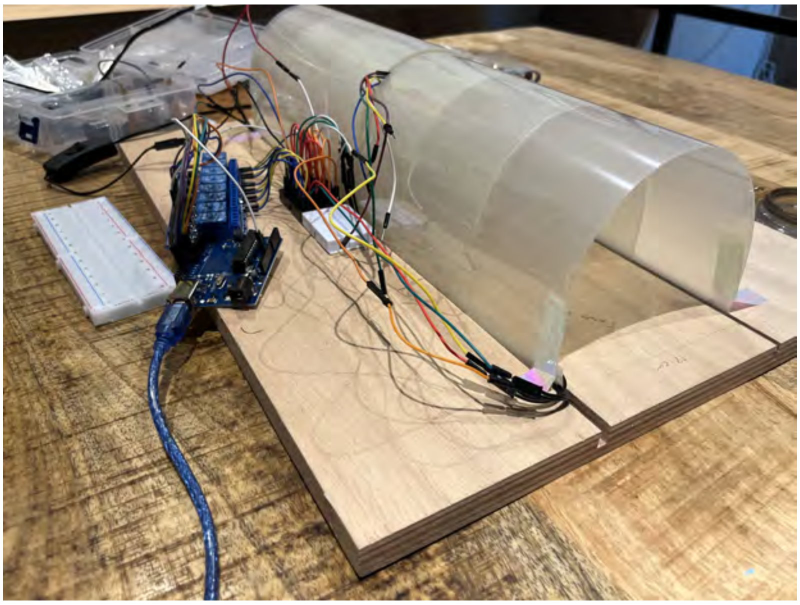

FIGURE 7.1: The shell of the tunnel

The internal design is also quite sophisticated. If only the space is simply separated and the body parts are suspended inside, the unease factor will increase. The lack of feedback leads to a decrease in interest and a transformation of experience into negativity. So, it is best for the interior to be relatively crowded, soft and elastic. The corresponding filling material is necessary. It is suggested that both ends should be closed off to prevent participants from peeking, so they are forced to use their own sense of touch to explore the internal space. It is worth noting that this block of eyesight can both bring a sense of mystery and trigger tension and resistance. It depends on the users.The use of smart film that reveals inner secrets can create a sense of wonder and unveil mysteries. However, this arrangement makes the whole design become disposable. Because once the secrets are revealed, it is difficult to arouse strong curiosity.

7.2 Implementation

The implementation of the tunnel form of design is from external to internal. At the surface level, I decided to overlap the smart film with three layers at the thickest part in the middle and only one layer on each side at the thinnest. This creates a gradient effect. In this way, it is clearer to see inside near the entrance, while even if all are powered on in the middle, it appears relatively blurry. The quantity of materials available determines the total number of layers. There are more layers, the control is more accurate and more natural. There are six sheets of film samples, which can barely form a simulation of gradient. All films are controlled by alternating current (AC), so I equipped a relay to achieve power control from Arduino programming - that is, transparency or opacity. These films are attached to transparent plastic cards and then fixed by inserting them into slots on both sides of wooden boards (Figure 7.1). The insulating material is wrapped between positive and negative electrodes of each film to ensure their independent control respectively.

After completing the production of the shell, I shifted my focus to internal production (Figure 7.2). At first, I tried to embed hand motion capture sensors on a wooden board. It utilises depth sensors and cameras, combined with image recognition algorithms to

FIGURE 7.2: The internal sensors and decoration of the tunnel

establish skeletal modeling of the hands. This allows for more precise control over the output of music or other complex elements based on hand movements. However, after testing, the sensors were unable to accurately recognise gestures due to limited internal space. In the end, two ultrasonic distance sensors were used instead and installed in the middle of the pipeline. They monitor the distance between objects on both sides respectively. Through programming, we determine the length of the part that needs to become transparent based on the depth at which the user probes into the pipeline, creating a gradual revealing effect. Finally, I installed a pressure sensor at the bottom of the board and covered it with a layer of white fluff balls. These fluff balls provide a soft and elastic touch. When users press on the fluff balls, they can affect the brightness of the light strip above the pipeline according to the force applied.

After completing the internal filling, two soft, small doors were made on both sides of the pipeline. The door consists of two layers. The interior layer is made of soft creased paper, while the exterior is made of elastic fabric (make use of hair ties). This way, the pipe opening allows hands to reach in but prevents visibility of the internal structure from outside. Then, all the sensors and actuators are connected by wires. The exposed breadboard, relay, and Arduino board are enclosed in a plastic case. After the software programming upload, only two power lines are left to supply power to the Arduino and smart film. The whole device became independent, and a laptop was no longer needed (Figure 7.3).

7.3 Workshop 3

7.3.1 Process

The tunnel form of Nudgo was aimed to give the participants chances to touch each other and maintain a positive feeling in this process. The workshop consists of three sessions. The same teacher, T0, acted as a facilitator and supervisor, and all the sessions happened in the same room. The device is put on a desk in the corner of the room far away from the door. Before the workshop, the teacher tried the system herself. Then, she leads one child into the room each time. The neurotypical participant T2 and the researcher are staying in the room near the system, waiting for different children to come in.

FIGURE 7.3: The prototype on the site of Workshop 3

Session 1

The teacher leads Child E to come in and holds her hand to the table with the device. Child E examines the device and then directly puts her hand inside. Then she takes out a plush ball from it, smiles, throws the plush ball on the ground, and then puts her hand back in. At this time, the teacher hints to Participant T2 that it is comfortable for Child E to share the system with T2. T2 approaches the table. Meanwhile, Child E remains focused on her own hand and gradually realises that the pipe is becoming transparent. She leans forward and bends down to look at the pipe seriously. Then she withdraws her hand a bit and tries to look inside from the opening of the pipe again, but it becomes opaque and she can't see anything. So she looks inside from above again. At this point, because both sides are reaching into it, their hands touch each other in the pipe, and then she glances at Participant T2 across from her. After glancing to the side, child E slowly withdraws her hand.

Then, child E walked away by herself to play on a nearby climbing frame. I can tell that she has already lost interest after five minutes because she keeps climbing up and down, fully engrossed in playing herself. So, I signalled the teacher to end this session. The teacher led her towards the door, and I walked up to the equipment and put my hand inside to rearrange the small balls inside. Unexpectedly, at this moment, Child E folds back herself and puts her hands into the tunnel again. Child E concentrates attentively, watching her own hand grab the balls inside while my hand is also shaking back and forth on this side. After playing for a while, she withdrew her hand and approached the teacher who was standing by the door. Together, they exited the room and the first session came to an end.

Session 2

The second child, Child F, was brought in by the teacher. As soon as he entered the room and saw the device on the table and unfamiliar people, he started shouting loudly near the door. He put his head on the ground and rolled around. The teacher gestured for him to come closer to the device, but he refused and continued shouting. In such a situation, I signalled T2 to sit down with me on the floor to reduce our presence and prevent further stimulation for Child F. The teacher led him towards the device while we moved away from it. He remained very angry and even hit the teacher's hand. It took some time for the teacher to calm Child F down. Then she pointed at the device to attract his attention, and Child F reluctantly reached inside and took out two small balls. Then he repeatedly asked to play soccer, so eventually, the teacher brought a soccer ball for him.

In a later interview, the teacher mentioned:

> "He has different expectations for different rooms; every time he comes into this room is about playing soccer; therefore when he realizes that there are other activities planned here instead of playing soccer it makes him very angry... This is his characteristic - he is extremely stubborn and insists on doing things according to his own expectations... For example, in the toy room, every time he wants me to give him the same animal book, which has become sort of like a ritual."

Session 3

The last child, G, was led in by the teacher. He seemed very interested in this device because after entering, he actively ran towards it and, without hesitation, reached his hand inside. At the same time, participant T2 placed her hand on the other side. Both of them extended their hands inside.

Child G immediately took out several small balls. He placed them on the table and continued to reach inside to gain more. At this moment, their hands touched each other inside. Unable to see what was happening inside from the top end, Child G tried to peek through the place where his hand went in. Then he looked at T2 and smiled slightly before taking out a few more small balls. After putting down the balls, he ran a lap around the room and returned to the device again. Then he became interested in a small light outside of the device and reached out to fiddle with it, causing poor contact with the light strip which then dimmed down.

His interest then turned into continuously reaching in to take out the small balls from inside. Finally, at the teacher's request, he put all the small balls back on the ground and then left the room with the teacher. The third session ended.

7.3.2 Observation and Analysis

Different reaction towards the hole

Both the teacher and participant T2 were hesitant to put their hands in when they first encountered this device. They carefully observed the outside, trying to know what was inside in advance. After the teacher put her hand in, she was startled by the clicking sound of the relay switch, but then she smiled - she found that she could see inside. After feeling around inside for a while, she took her hand out. She described it as a thrilling yet safe experience. It can be understood that at first, she was nervous and became sensitive (such as overreacting to sounds), but then she realised that she was safe and found it interesting.

The reactions of the children were completely different. When facing this device, all three children did not hesitate to reach their hands. Their speed of reaching out was fast, and often, their gaze wasn't fixed on the device itself but rather looking aside as if they were trying to perceive touch with great concentration. Even though Child F didn't want to participate in this activity very much, his behaviour wasn't due to tension about reaching

FIGURE 7.4: The same peeking behaviours of the children towards the hole

into an unknown space; instead, he expressed complete dissatisfaction with engaging in a new activity. When he reluctantly reached out his hand just to please the teacher, it wasn't an exploratory hesitation but more of a cold indifference putting his hand in. Often, their reaction to the process of surface becoming transparent is not very strong; it appears that they are more focused on their hands.

There are two explanations for this situation. One is that children have more sensitive tactile sensations than adults; in other words, they do not rely on vision as much as adults do, so they do not feel strong anxiety and tension when their vision is blocked. Consequently, they also do not become overly excited when their field of view is restored. The other explanation is that children have a stronger curiosity for exploring new things, which overwhelms their fear of the unknown. Therefore, when they discover an accessible hole, their first reaction is to put their hand inside it.

Observation of the behaviour patterns

The behaviour of children has many similarities, but it is different from that of adults. First, when children reach in for the first time and take out their hands, they will always dig out the small balls inside. The small balls are fixed on the wooden board with glue, but they are loose and can be easily taken off with a little more force. However, adults often do not do this; they have a sense of not wanting to destroy this device. Children's desire to take out and see what they have touched is obvious. Moreover, after taking it out and looking at it for a moment, all their reactions are to throw it away - letting go and placing the small ball on the ground or table. Although some children may pick it up again to play with it later, throwing it away is an action that everyone does. Second, when children reach in to explore after already digging out a small ball once before, they often bend down and try to peek inside from the hole where their hand goes in (Figure 7.4). This shows their curiosity towards the things happening inside. This usually means that they have touched something different.

Participant T2 stated in a subsequent interview that most of the time, she was observing the reactions of the children across from her. This is consistent with the state of T1 in a previous workshop. Their attention was not focused on themselves but rather on the reactions of others. On the one hand, this reflects that the feedback from the device itself may be too boring or lack variation to attract enough attention, quickly losing its freshness; On the other hand, the presence of an autistic child participant who is difficult to grasp and understand during the interactive process naturally captures the attention of neurotypical adults.

A redundancy of consciousness can seemingly explain this. Participants T2 quickly gain an understanding of the mechanism of the entire interaction, feedback from the device, and atmosphere; they often rapidly complete a modelling loop from their perception to their own behaviour and corresponding feedback. As a result, their cognitive resources are not completely occupied by their current engagement. They do not enter a state of flow. Therefore, they naturally shift their attention to participating objects across from them. This often occurs because those actions differ from their own and elicit instinctive curiosity.

T2 also mentioned that she was touched by G's hand inside the tunnel, but she felt that this did not generate a clear sense of connection. This impression is consistent with my observation of the experiment's video recording. Among them, Child G's hand reached the farthest into the depths. Therefore, Child G also spent the most time in skin contact with T2. Child G would look up at the other person, but this gaze did not last long. It is normal for NT participants to ignore this signal, or rather, researchers tend to amplify this signal as a clear sign of connection. This touches upon the essence of the Double Empathy Problem - both sides are unable to receive each other's signals of connection.

7.4 Reflection of Tunnel Form Nudgo System

The Nudgo System, with its tunnel-form design, is a device worth exploring. Users can enhance their understanding of the device by actively engaging with it and physically interacting. As users invest energy in adapting to this innovative system, they immerse themselves in a fresh environment where both sides adapt to each other's presence while discovering new things. The process of exploring what the device is and how it is used is often proactive and positive. Such exploring features can be more effective for autistic children with an open mindset. For neurotypical adults, this exploration process happens very quickly. The equipment lacks competitiveness in terms of continuous curiosity and reusability.

In three workshops and interviews, I found that children have very limited interaction with neurotypical adults outside of their teachers and immediate family members. Most of the interactions occur in activities with specific purposes, such as interacting with a hairdresser during a haircut or with a doctor during a physical examination. Based on these situations, there is not a significant user demand for connecting autistic children targeted by this project with neurotypical adults. Activities with specific purposes typically do not prioritise establishing deep emotional connections but rather focus on fulfilling practical objectives. While building connections can have long-term advantages, both parties often lack the motivation to invest time and energy in doing so. In such situations, teachers frequently rely on direct soothing, hugging, or offering rewards solely for the successful completion of specific tasks like haircuts or examinations.

After Workshop 3, the teacher mentioned her strong desire for toys that can be shared among the children to promote interaction between them. She often provides individual guidance to children and offers various toys to teach them how to use them so that they can share what they have learned within a group setting. However, she believes there is still significant room for improvement in sharing behaviour within this group setting. Therefore, toys that can be shared with autistic peers during leisure and free playtime become a potential future research direction other than the interaction between autistic children and neurotypical adults in this school context.

Chapter 8

Future Design

8.1 Overview of the Strategies for System Design

In Chapter 2, we proposed four principles for system design. In the design practice, some design strategies are developed. These strategies were categorized according to the principles. Plenty of reflections have already been discussed in narrating the process of design iteration. In this section, we attempt to provide readers with a comprehensive answer to sub-research question 3, "What are the design strategies we can use to design this system for neurodiverse social connections?".

8.1.1 Senses

Principle 1: explore multiple senses or unrepresented aspects of the body.

Strategy 1.1: induce the body into open and expansive postures.

The effects of the embodiment can go beyond emotions and cognition, reaching physiology and subsequent behavioural choices. Carney et al. discovered that engaging in high-power poses can lead to a range of physiological, psychological, and behavioural changes [16]. High-power poses are measured by their expansiveness, which refers to how much space the body occupies, and openness, which pertains to how open the limbs are. Open, expansive postures can increase the dominance hormone testosterone, decrease the stress hormone cortisol, and enhance behaviorally demonstrated risk tolerance and feelings of power. This is an important factor in the situation of neurodiverse interaction. With fewer resources and marginalisation of the social group, neurodivergent people, such as those with autism, have higher chances of feeling chronically powerless.

Cuddy proposed that by simply changing physical posture, an individual can prepare his or her mental and physiological systems to endure difficult and stressful situations, and perhaps to actually improve confidence and performance [21]. This explains that in Workshop 1, even without obvious rewards, the participants immediately smiled when just waving their hands. Participants spent most of the time expanding their arms and chest. This can directly reduce their level of tension and enhance their level of pleasure. The strategy is consistent with our original intention of alleviating the initial sense of tension in the wall from the Nudgo System. It should be considered in similar designs afterwards, especially in situations where there is a significant power difference between both parties, such as adults and children.

Strategy 2.2: play the role of visual and auditory stimulation together.

All iterations of designs introduced both visual and auditory elements. In wall-form Nudgo systems, music is embedded into the feedback loop. In the tunnel-form Nugdo system, the sound of a folk guitar is played as background music for the workshop. However, many RtD types of research focus on certain senses of human beings; such pure exploration is rejected in this project for the following reasons. First, our five senses are constantly receiving information or energy from the environment at every moment, although the weight of stimulation brought by different senses may vary. Even if specific sensory experiences are not the intended focus of design, as a holistic experience, designers still need to consider the impact they bring as environmental factors. For example, in tunnel form, we did not specifically design sound outputs. However, when the relay component is operating, it emits a clicking sound due to current switching. This clicking sound can be very abrupt in a quiet room. Therefore, selecting and matching appropriate ambient music for the working system becomes important. Furthermore, since we do not know how exactly users would use their own sensorimotor sensemaking, it is important to cover multiple senses at the same time.

Strategy 2.3: trigger novel tactile experiences with mysterious space.

In the tunnel form design, we explored some innovative experiences that are not typical of tactile feedback. Such an experience is created together with visual stimuli of the tunnel surface. When the participants enter this tunnel with their hands, they will be able to see the changes on the surface. After initially using touch to explore, more places gradually become visible visually. This alternating process of exploring with different senses can trigger a noticeable curiosity. Furthermore, if progressive levels are added, such as generating different lighting effects with hand movements or triggering music effects with mutual touch, the entire experience will be more lasting, the playability of the device will be higher, and both parties' involvement will be deeper.

8.1.2 Mediator

Principle 2: person-to-person dyadic interaction is prioritised where the system serves as a mediator

Strategy 2.1: support equality and balance through symmetrical design.

Symmetry is maintained throughout the design process as it is primarily aimed at two-person interaction. All the designs are both left-right symmetric and centre-symmetric. This creates balance, and balance creates the beauty of harmony and stability. In the design of the wall form, users can get engaged to the same extent on any side. In tunnel form, the entrance provided is narrower, and symmetry is more pronounced. Both parties are thus forced to be placed on a completely equal starting point by the device. Therefore, we can observe some compromises and adaptations made by users, especially adults, in the workshops. For instance, all neurotypical participants kneel down to adjust the height of the screen or the tunnel. This damages the user experience to some extent, but it may be beneficial for enhancing the relationship between both parties. Further design improvement can focus on how to adjust while maintaining this symmetry to ensure user comfort in body posture.

Strategy 2.2: provide safety and control through spatial separation.

Observation reveals that the design of symmetry forces participants to maintain a face-to-face posture during the interaction process. Among familiar friends or loved ones, this body posture appears more intimate and without reservation. This is disadvantageous for both parties who are not very familiar with each other in terms of signals from the torso. Generally speaking, in conversations or interactions with unfamiliar individuals, a face-to-face angle of 0° may appear unfriendly and aggressive. Standing opposite each other makes it easy for gazes to converge, leading to strong feelings of insecurity for both parties. This may have an even greater impact on highly sensitive individuals within the autism spectrum disorder community. Usually, it is best to design the body angles of both parties to form a right angle.

In the design of wall form, due to the design of sharing screens on both sides, it is not very likely to have a straight posture design. At this time, in such an excessively intimate and overwhelming interactive relationship, it is important to provide a mechanism that creates a sense of security. In direct competition or situations with a sense of attack, human body language tends to be self-protective. Once this unfriendly body language is formed from the beginning, the relationship between both parties becomes tense from the start. The further development of rapport will be inhibited. Therefore, blocking part of the line of sight and providing spatial separation will be relatively important.

In addition, in the design of the tunnel form, both sides are face to face. This is actually another form of spatial separation. The space is divided into interior and exterior. When users focus on the interior experience, their attention to the exterior will correspondingly decrease. In other words, this spatial separation reduces the pressure of directly facing or confronting each other. Moreover, the design of the tunnel not only connects them but also provides a visual focal point. This is different from the direct line-of-sight barrier brought by semi-transparent screens; it provides a sense of security through visual displacement.

Strategy 2.3: create a harmonious and pleasant atmosphere through action mirroring.

One important role of design as a mediator is to guide the emergence of coordination in an unconscious way. Coordination is a driving force for participatory sensemaking and an important factor in building rapport. In face-to-face interactions, coordination often appears through mirroring or synchronizing actions and facial expressions. Mirroring is different from conscious imitation, which involves intentionally and openly copying another person's behaviour. This deliberate imitation can potentially lead to the other person feeling averse. Mirroring behaviour allows the other person to perceive the similarity between each other, and this similarity can create a sense of belonging for both parties, serving as the foundation for establishing a relationship. A vivid example is the double dancing mat. Even without physical contact or proximity, completing the dance together quickly brings both parties closer psychologically.

Symmetry design is very advantageous in constructing this kind of mirroring behaviour. Not only do both sides have a high probability of performing similar actions, but also because they are face-to-face, it is easier to visually perceive each other's movements. The limited visibility and restricted hand movements in tunnel form design hinder the synchronisation of actions, making this advantage less apparent. In the design of wall forms, the unconscious mirroring actions caused by large-scale movements are more noticeable.

8.1.3 Structure

Principle 3: offer structures without relying on complex behaviour or language interpretation.

Strategy 3.1: bring physical texture with the help of touchable and soft objects.

Providing structure should provide a sense of trust and stability. However, asking users to adapt to a new structure inevitably brings about a certain degree of distrust and instability. In the design iteration process, attempting to create a structure by providing clearly defined steps may sound reasonable but is often superficial. Games or programs with explicit steps tend to be coercive, requiring significant compromises and concessions from users. Extreme examples may occur in cases where individuals are highly sensitive to unexpected situations. For example, in Workshop 3, Child F resisted participating in the workshop activities in the gym room. He had created his own structure, such as playing balls in the gym room and specific toys in the playroom. When we tried replacing his existing structure with a new one (the Nudgo system), due to a lack of intrinsic motivation, his behaviour exhibited resistance (intense rolling and shouting) and compliance (passively inserting hands into the device). In states of resistance or compliance, positive interaction with others becomes impossible.

To provide users with a comfortable structure in such difficult circumstances, it is necessary to shift thinking from a machine-like perspective to a biological perspective. Soft textures and rich surfaces, such as fabrics or grass, should bring more comfort and intimacy compared to hard and smooth surfaces. Contact comfort is a crucial factor in the development of affection or love. In Harlow's research on the development of infant monkeys' affectional responses, it was discovered that this need for satisfactory body contact could overshadow nursing entirely [38]. In Workshop 1, we also discovered a natural affinity for soft objects. For instance, child B brought two stuffed toys halfway through and held them in his hands. In the module 2 session, he repeatedly used his hands to slide on the cloth that served as the screen. Further research is needed to verify the function of soft materials in attracting and comforting users.

Strategy 3.2: use immediate sensory feedback to replace instructions.

The system design aimed for an initial stage without instructions. I hope that the placement of the system itself can attract users to explore, and once they approach, they can receive feedback. This is reflected in the first design iteration as activating the music module once a user is detected, as well as a series of automated recognition modules mapping hand movements. In other words, the existence of the system itself serves as guidance. The system conveys what needs to be done through its placement and the information it provides (such as images but not texts on the screen).

However, in the workshop, this type of feedback often lacks clarity. As a result, there are still many situations where teachers need to provide instructions to children. For example, in Workshop 2, Child C was initially attracted by the cubes on the screen and actively attempted to interact. However, instead of using her hands, she relied on her head to control the ball on the screen. This surpasses the system's capability to respond. At this point, the teacher intervened proactively. This situation shows that the feedback mechanism is not mature and there are disadvantages to relying solely on one feedback loop. However, I still believe it's better to use system-generated instant feedback instead of manual guidance in the beginning stage. This can prevent issues caused by intermediaries like teachers acting as mediators for feedback.

Strategy 3.3: allow the level of participation to be adjusted flexibly through body position.

Although the designs of the two forms (wall and tunnel) are completely different, they both attempt to provide users with a hidden logic based on location to control or express their level of involvement. In the wall form, the level of involvement based on location can be divided into three levels. One is active involvement close to the screen, followed by being at a certain distance from the screen but still able to control the participation range

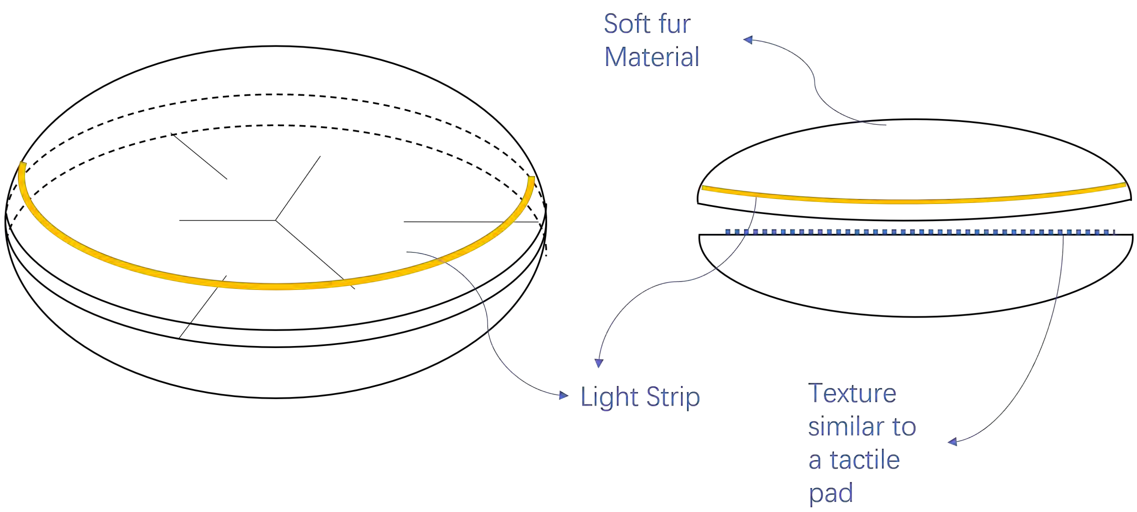

FIGURE 8.1: Future design of the Nudgo system: a double-layered UFO-shaped smart plush cushion

FIGURE 8.2: The tactile pads

of the balls on the screen and finally, observing from a distance without direct interaction with the screen. Compared to the design of wall form, tunnel form is not based on the position of the whole person but rather on hand position. The level of involvement can also be divided into three levels: not reaching into it from the outside, reaching in but not further exploring inside, and diving in or even crossing over halfway through. However, in tunnel form design, participants are more likely to completely give up their attention to the system compared to the wall form design.

Participating in this location-based autonomy of engagement is a gradual process, rather than a simple yes or no. In Workshop 1, Child B repeatedly moves away from and returns to interaction with the system. This actually creates possibilities for further interaction. Furthermore, the levels of engagement based on location are consistent with the levels of intimacy in direct communication between individuals. This characteristic allows participants to engage more deeply with the design process while also getting closer to another participant.

8.2 What a Future Design Looks Like

For future design, one idea is to create a double-layered UFO-shaped smart plush cushion with a gap in the middle for inserting palms or entire arms (shown in Figure 8.1). To ensure comfortable lying and arm movement for children, whose arm span is about 1.1 to 1.3 meters, the cushion's size is designed to be approximately one meter in diameter. The circular shape and larger size also make it suitable for multiple people to share. The exterior is made of soft fur material, while the interior gap has a tactile pad-like texture (Figure 8.2). The remaining space is filled with soft elastic fiber material.

The upper layer of the cushion contains pressure sensors, while touchable materials inside are connected to capacitive sensors that detect hand positions. A ring of light strips is embedded near the gap area. Pressing the upper part of the cushion causes edge light strips near the pressing point to emit light; as pressure increases, the color gradually changes from blue to green, yellow, and red.

By inserting palms into it and moving positions inside, users can control synthesized music. This allows collaborative music and lighting effects to be formed simultaneously.

In the exploration of future design, special attention should be paid to the following three aspects: target user, interactive scenarios, and introduction scenarios. I will elaborate on how this design idea meets the needs of these scenarios in each of these three aspects.

Target user: children with autism aged 6-10 years old.

This structural shape provides flexible adaptability for children's playtime activities. It can be placed on a table for touching, pressing against or resting heads on top; it can also be placed on the floor for stepping or extending feet into it. The soft, skin-friendly external material provides a stable and reliable sensation; meanwhile, differences in textures between internal and external surfaces themselves bring certain tactile stimulation. Additionally, inserting arms into it can provide a sense of wrapping around, which enhances bodily sensations.

Introduction scenario: Under the guidance of adults (teachers or parents)

The target audience for this product should mainly be school organizations or parents. This means that when introducing this product for the first time, parents and teachers may have their own ideas about how to use it. Therefore, the design should pay attention to the psychological appeals of adults purchasing toys (such as a desire to interact with children and wanting to help them improve social skills), and incorporate them into the design. In addition, the production cost also needs to be controlled, for example, try to use small and common sensors. Washable pillowcases can be provided to increase durability.

If parents are buying this product, then it mainly serves as a medium for interaction between parents and children, to be used within the family environment. Its diameter can be controlled to be smaller, approximately 0.8m, but the thickness can be increased. If in school, the teacher provides this toy to the children. Even if its purpose is to promote interaction among the children, the teacher will actively participate. Therefore, it should be able to accommodate multiple people at the same time and can be enlarged in size.

Interactive scenarios: Focus on the interaction between children with autism and their long-term peers, aiming to create opportunities for social interaction and natural self-expression. Examples include interactions between different children with autism in special schools, interactions between children with autism and non-autistic children in inclusive schools, and interactions between children with autism and their parents at home.

This interactive scenario requires the product to have a certain level of portability and be easily shareable. The large devices previously tried in this project were fixed on the ground or tabletop, with many electronic devices connected, so they couldn't be moved freely. Therefore, participants had to adapt to this fixed position. In future designs, even if there are embedded electronic products, they should be rechargeable and wireless.

In addition, sustainability is another indicator. This means that this design can be played with repeatedly and used regularly. Based on the basic continuity of sound and light feedback, some additional game mechanisms can be added according to the interactive context. For example, a tapping game similar to whack-a-mole. After adjusting to enter the game mode, a red light at a certain endpoint lights up, and it needs to be pressed in the nearby area to make it disappear. There will also be a reward prompt after pressing it. Such mechanisms

Chapter 9

Discussion

9.1 Evaluation of the Project

9.1.1 RtD Project Evaluation Metrics

Although a reliable basis is available for the reasons for conducting RtD, there is no consensus on how to assess the quality of RtD projects and their outcomes. However, even in such a new and complex context, we can still identify certain qualities of a relatively good RtD project from some existing cases. This includes having a traceable process, producing innovative and defensible results, and making contributions to theory and practice. Prochner and Godin have proposed a framework of research quality indicators for RtD projects [62]. The authors summarised these indicators by identifying a shared vision in their systematic review of recent research on RtD. Overall, they categorised 14 indicators into five categories: traceability, interconnectivity, applicability, impartiality and reasonableness. In such a young field, this relatively new framework cannot be considered an industry standard, but it provides us with a comprehensive perspective for evaluating my project. I will analyse the strengths and weaknesses of this project based on these indicators one by one as a systematic answer to sub-research question 4, "How can we determine the success of the system?".

Traceability

In this category, two indicators are proposed to evaluate traceability, which refers to the ability of this project to be reproduced in a direct manner. These two indicators are *replicability* and *recoverability and transparency* [62].

The nature of RtD projects determines that the final output does not pursue replicable experiments, as they are not intended to solve a general existing problem but focus on specific future scenarios. However, *replicability* is still emphasised because even if each designer may not adopt exactly the same design strategy when facing the same problem, the completed design process should be reproducible. This poses requirements for presenting design outcomes. In other words, even if readers do not replicate such designs in the same scenario, the way information is presented should ensure that readers are aware that the data is complete and available for use while reading. From this perspective, the presentation of this research is comprehensive in terms of describing the design and implementation processes as well as experimental procedures. Although there may be some selectivity in narrative details provided by the author, the organisation of material based on activities (the swimming pool framework) ensures that all essential elements of the entire project are documented.

If the *replicability* evaluates the exact steps to get the results, *recoverability and transparency* are more focused on the internal logic of the whole project. It is centred on the question of "why and how the research is done". It requires the project to explain to readers how the conclusions have been reached so that the final results are not surprising to the readers. The transparency of this project is based on detailed workshop records, without the researcher's bias in selecting favourable parts to prove the system's effectiveness. Furthermore, the connection between the purpose and the process was clear. The decision process of the system features selection was described in the design and implementation activities. However, certain weaknesses can also be found in the research. There was chaos in the initial ideation and design phase in the wall form design, which was briefly mentioned in the content. The generation of the ideas is untraceable since they are more based on the discussions and self-experience of the designer. It is also related to the lack of clear research questions at that stage. Moreover, some of the design decisions can also be affected by factors that were temporary or difficult to discern at the time. For example, the shift of the wall-form design to tunnel-form can also be affected by the subjective preference of the designer and the availability of devices. Sometimes, it is hard whether these factors are accountable and should be included in the thesis.

Interconnectivity

The interconnectivity category focuses on linking elements of a project, such as concepts, variables, stakeholder viewpoints, and the research environment. The indicators include *internal validity*, *credibility*, and *contextualisation*.

The *contextualisation* is a fundamental aspect of the RtD project and it is emphasised in this research. In the project, the background of the whole research team, participants, and environments are detailed and introduced. It's easy for readers to identify the context-related factors in this project and their relationships to the consequences of doing research in this context. For instance, the workshop room was used as a gym, and such a function of the room is closely related to the expectations and behaviours of the children in the room. It makes it easier for them to feel free to dance, but, at the same time, it is distracting for them to focus on the workshops. The contextualisation of the project is generally solid and detailed.

Internal validity indicates the level of confidence in the cause-and-effect relationship between variables. The whole project was weak in this indicator. From the perspective of the connection between the variables and results of the research, this project gave a good explanation of the space relationship between the participants and the system. Certain elements in the workshops, such as the role of the teacher and the sync movements, were analysed in different workshops. However, when considering the construct validity of the data collection procedure for observing the links, it becomes apparent that some of the identified links are ambiguous and uncertain. For instance, some workshops only have one to two sessions. The infrequent repetition of sessions and an insufficient number of participants make it difficult to consider certain observations of the link as valid patterns.

To make the project *credible*, participant validation is essential. Such validation is more prominently used in co-design projects than others by directly involving the participant in the evaluation process. For instance, some researchers proposed participatory evaluation methods that include a series of activities such as co-definition of goals and methods, joint processes of data gathering and the co-interpretation of results [76]. The validation of this project is mainly based on the analysis of the video recordings of the workshops. Some participant validation is done with the help of the teacher on the site. After each workshop, the researcher interviewed the teacher about the observed children's reactions. The teacher would give the interpretation based on their existing experience of the children. However, this validation, combined with observation and the teacher's interpretation, can not fully represent the children's own feelings. A potential improvement can be further verified with the participants and other teachers if the interpretations are accurate and well-constructed.

Applicability

This category focuses on whether the research results are applicable beyond the original research context. This includes *external validity*, *transferable*, and *impact*.

External validity stresses that design results are generalisable and can be applicable to other contexts. It is a less natural indicator for RtD projects as it conflicts with the indicator of *contextualisation*. This project is largely dependent on the context, including both the participants and the environment. The prototypes generated in this research can not be considered to have strong external validity.

Design ideas and strong concepts, not only the results, can provide insights between projects. *Transferability* assesses the applicability of outcomes from a broader knowledge side. Different from *external validity*, *transferability* acknowledges that certain results may not be universally generalisable. This research gave a detailed discussion of the strategies summarised from the design process. Combined with the detailed research context description, it provides a solid foundation for readers to estimate the transferability of this project to their situation. However, to evaluate the extent of the transferability, it is very important to have evaluations from researchers doing other RtD projects rather than just self-evaluations.

The measure of *impact* is not only about sharing knowledge within the field of RtD projects but also about the positive improvements it brings to the group and even the entire community where the design object is located. This is what most RtD projects focus on. Impact can be considered from both the depth and breadth of influence. The target group for this project is primarily children with autism. In addition to the children themselves, relevant stakeholders include their teachers, therapists, families, schools they attend, and communities they live in. The depth of the project can be evaluated by considering how participating children and teachers perceive and experience the related designs, as well as observing long-term effects on their lives through follow-up surveys and interviews. For example, deploying completed designs for daily use in schools and observing changes in the relationship between the children and the teacher. The breadth of the project impact can be assessed based on its potential impact on a larger population. Whether it triggers extensive discussions and attention is also an intuitive indicator. Overall, this project has had limited impact. Being a short-term endeavor, it has not received ongoing research or made a significant impact on the community.

Impartiality

Impartiality focuses on the bias of the researchers. It includes indicators like *objectivity*, *confirmability*, and *contextualisation in theory and research*.

Objectivity and *confirmability* both demonstrate that the researcher has not influenced the data collection. When discussing the objectivity of the project, it stresses that the researcher and the observation results are completely detached from each other. In this project, the researcher played the role of participants in Workshops 1 and 2. Such interference in the experiments can be considered not objective at all. Confirmability, on the other hand, shows that the researcher's biases and expectations are controlled to avoid influencing the results and process. The project indeed shows an attempt for confirmability, though not achieved. For example, the researcher tries to separate the observation and the interpretation of the results when describing them in the thesis. However, due to interference in the workshop, it is difficult to eliminate subjectivity from the observation results. In other activities like ideation and design, subjectivity and bias of the design researcher are welcomed instead of suppressed.

The indicator of *contextualisation in theory and research*, different from the contextualisation indicator under the interconnectivity category, ensures the theoretical context of the research is solid. It requires the researchers to use accepted knowledge to explain the research choices and findings. In this research, embodied and enactive theories are applied as the conceptual models to frame the design development and on-the-site experience. The project extensively utilises such connections to theories. Such roots in the theories can give the project a clear positioning in this region.

Reasonableness

Reasonableness cares about establishing a repeatable process for design practice and explaining design norms. This category includes *reliability*, *dependability* and *soundness of research methods and research norms*.

Reliability means making reasonable choices in research and measurement approaches, resulting in consistent results during retests. Clearly, the Nudgo system design lacks a set of measurement indicators. While some aspects of rapport and intimacy are considered in the design reflection, a systematic and comprehensive measurement system has not been established. It was found that measurement is uncommon in RtD projects [62]. Considering the different contexts, constructing a systematic measurement seems both laborious and unrewarding. This is because it is difficult to transfer the measurement standards used in current research to other studies. In this project, design directions are emphasised more than system evaluation from an analytical way. The workshops' aims were viewed as a process of improving the design rather than a final outcome testing. The measurements were consistently overlooked and postponed.

The indicator *dependability* requires the theoretical inferences to be justified. This can be demonstrated through the external audit of the research findings, which shows the research process to be reasonable. This project is generally based on the theory implication. From this perspective, theoretical inferences in chapter 2 are cautious and comprehensive. However, the theory parts during the design process are not always clear and explicit.

To measure the alignment of the project with accepted norms in the field, the indicator *soundness of research methods and research norms* is introduced. This project hosted participatory workshops, which were inspired by research and design practice methods. Widely used qualitative research methods, such as interviews, are included, but this project relies more heavily on design practice methods as a means for knowledge generation. But even RtD projects using standardised design practice approaches are unique in their own way. According to this indicator, this project's research methods and norms are very sound.

9.2 Further Discussion

9.2.1 Design Process Reflection

The lack of agreement in RtD evaluation can result in various problems. At the beginning of this project, the lack of explicit guidelines made it hard to plan the whole project. And because the standards of measurement were not clear from the beginning, this also led to the researcher unconsciously relying on intuition to guide the design. In the cases of most research paradigms, which have clear standards, it is relatively easy to obtain results through controlled experiments and data analysis. Their results are also more convincing. However, in the RtD projects, researchers can rely more on intuition and thus be more creative [36], but it is difficult to guarantee precise adherence to the initial objectives. More importantly, in the latter case, researchers will be required to prove their methods excessively, making it difficult and lacking a basis when explaining their results to researchers from other fields.

Furthermore, this absence of standards or benchmarks makes it difficult to trust and sustain the results of RtD research. For example, at the beginning of this project, even though there was relative consistency in the focus of previous student projects, no member of the team directly continued their research based on the results of the previous projects. Team members each proposed their own points of interest, with reference to existing projects mainly reflected in research methods and design strategies. Such avoidance is, on the one hand, because the existing design prototypes were poorly preserved and complex to reproduce and, on the other hand, because the research context is not entirely consistent. However, it is clear that the knowledge in RtD projects is spread and developed in a low-efficiency way. This leads to a lot of repeated work and wasted energy in this field because similar studies are repeated unnecessarily from the perspective of the entire field.

The obstacles to knowledge transfer and diffusion across RtD projects can be the price of the growth in capabilities and experience of individual or team researchers. Seemingly repetitive work is unique to researchers as first-hand experience. For every researcher, proficiency in using the RtD method requires a process that includes imitation, practice, and exploration in order to transition from ignorance to expertise. In experimental systems with relatively fixed procedures, researchers have fewer things to decide and consider at the beginning. The feedback is clear, making it easier to delve into a specific problem and achieve noticeable results in the short term. In the RtD project, the breadth and depth of one's learning can be expanded at the same time. Perhaps progress was slow at the beginning due to a vague direction, but in the long run, it is a very valuable opportunity for the training of design researchers. If we shift our perspective from being project-oriented to researcher-oriented, the process of doing an RtD project can also be viewed as a design researcher's competency-based learning process. According to Hummels and Frens, competency-based learning is a personalised process that varies based on individual and contextual factors [45]. Overall, this process emphasises integrating knowledge, skills, and attitudes through practical application and reflection on action. Accordingly, a reflective, transformative design process (RTDP) model is proposed to support such a learning process [45].

The RTDP model summarised five activity categories. As shown in the Figure 9.1, the central circle represents the core activity of the process, which emphasises *ideating, integrating, and realising* interaction solutions between users and products/systems within a specific context. This activity corresponds to three activities in the swimming pool model: ideation, design, and implementation. Above the central circle is *envisioning and transforming*, which is included in the theory lane. Below the central circle is *validating quality*, which equals workshop activities. The two remaining circles (*sensing, perceiving and doing* and *analysing and abstracting*) focus on the different skills the designer utilises to create solutions, including cognitive skills as well as perceptual-motor and emotional skills.

The RTDP model offers a new perspective for researchers to evaluate short-term RtD projects themselves. For instance, the envision circle indicates that designers must not only develop the next generation of digital products but also determine the type of life

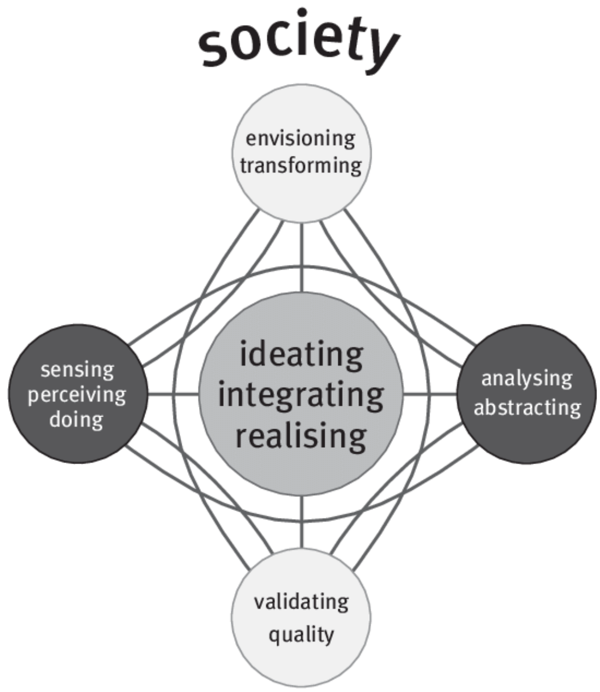

Figure 9.1: The reflective, transformative design process model

and society these products should support. What's more, it requires designers to identify whether they are relying on intuitive instincts or logical reasoning when it appears that they are contemplating something. This awareness can help designers know the strengths and weaknesses in their thinking process by evaluating the proportion of effort they put into these two activities and further balance it in the next iterations. It also places special emphasis on reflection. The model suggests that all activities are connected through reflection on action, which allows for a continuous gathering of information and gaining insight into the design opportunity and solution domain. In conclusion, this model can serve as a timely reminder and a powerful tool for design researchers to reflect on and enhance their abilities.

9.2.2 Suggestions for Beginners

There is a big gap between understanding the RtD method and actually practising it. I will briefly summarise my own lessons as follows, mostly from the mistakes I made in this project. While it wouldn't alleviate the challenges one might face, at least he or she wouldn't overreact when confronted with them so that sustained effort becomes possible.

To begin with, to learn is to change. For any long-term change to happen, one must be open to negotiating with his or her resistance to change. It means to be willing to look foolish, to use pain as the best guide for their performance and to have a determination to keep pushing with awareness. Deliberate practice and consistency are precisely the core of making progress in RtD projects. Making mistakes quickly, reflecting on them, and accumulating experience are the mechanisms that differentiate the RtD approach from other methods in promoting creative generation. Inexperienced students often face a huge gap between their ideal design ideas and the actual results. The tendency to fantasise about seeking attention quickly and making a lasting impression on others can easily lead to strong frustration. It also hurts the attainment of a concentration state. Be cautious about that tendency, ask for help with boldness, and do not let the strong frustration and confusion consume the determination.

Second, greatness cannot be planned. If a designer finds that some of their creations fail to truly impress users, it's either because they are blinded by an idea they believe to be irrefutable or driven by an emotion they feel compelled to express. In such cases, sooner or later, dilemmas and stubbornness are bound to arise. They may struggle with finding alternative solutions when faced with technical and material limitations. They then attribute their unsatisfactory results to environmental factors. Alternatively, they may turn a blind eye to obvious issues during workshops while fixating on achieving a particular striking effect. On the other hand, designers who can genuinely create great products are often moved by a strong desire to captivate users. This passion becomes the source of creativity and courage in overcoming challenges.

Third, bad design decisions are usually not because of bad imagination but because the questions were not explained well. If someone finds the research boring, it's likely because he or she either picked a topic that doesn't interest him or her (and makes no difference to others) or approached a good topic in a mediocre way. Novices often do not want to spend enough time to thoroughly explore the research questions and choose the topic that is important to them. There is a misconception that hinders students from giving up on research questions they initially deemed important but later found to be less significant, as they worry about wasting their time and energy before doing so. The change in research questions does not mean losing the value of the previous research process but discovering something more valuable. Carefully documenting the shifting processes helps us see the path of our own thinking and facilitates sharing with others.

Last but not least, make yourself interested and enjoyable. The design object of RtD is often not the designers themselves, but regardless of the degree of overlap between the designer and the user group, they should be able to find ways to derive enjoyment from it. Grimness and solemnness are not that helpful. When designers become deadly serious, they suffer from tunnel vision. Mistakes are seen as punishments, and the inability to achieve ideals makes previous efforts seem worthless. Proper relaxation and humour not only alleviate the burden but also expand one's perspective.

Good luck!

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Appendix A

Information Letter and Consent Form

<date>

Information Letter (EN)

Dear teachers and parents,

Thank you, again, for your interest in partaking in our study. In this letter, we would like to inform you about what your students'/children's participation in our workshop sessions will entail, for you to have a clearer understanding.

Our Aim

Our goal is for your students/children to have playful interactions with one another though the different games they get to play. Besides having fun, they would be helping us, as a part of our final research projects, to design a technological system that can improve collaboration and enjoyment in neurodiverse settings in the near future.

What?/Workshop Contents

Specifically, the research we will carry out during these workshops is about childrens' experiences of different sensory inputs (e.g. sounds and touch). We would like to create products that best suit their needs in this sense and therefore want to get valuable insights through these sessions.

The participants will each be in max 3 workshops. In total each of these workshops will take a maximum 90 minutes long, between now and summer 2023. For each workshop, there will be sufficient breaks in between. The participant can always choose to join only one or several of the three workshops. In the workshops, the children will work in pairs. The sensory inputs mentioned will be included in objects (like a bracelet) the participants can hold or wear and the participants. The participants do not need to touch things they insist on not touching and can leave at any time. The sounds that the participants are objected to will be in normal hearing range and will be discarded/changed in case of any discomfort.

Informed Consent & Withdrawal Possibility

As the participants will be minors, the formal consent will be given by the parents and/or the school (representatives)/teachers, alongside their voluntary participation, for them to participate in our study.

In case of a wish to withdraw from the study, the participants will need to inform the workshop facilitators (Lara or Purna). If one does not want to participate anymore, this can be done during the sessions at any point. If the participant wishes to withdraw from the study after it has been conducted, the participants' guardian can email Purna Bishas, stating this situation.

The Nature of Research & Potential Risks

The research is not medical, it is not about a medical therapy or medical procedure of any kind.

The sessions are completely safe without any risks for the participants personal/mental health, as the research project has been reviewed by the Ethics Committee Information and Computer Science to ensure this.

Data Privacy & Protection

The data will be recorded/stored for research purposes on a laptop, password-protected and accessible only by the researchers themselves. This data will be saved in a safe research drive after the research has been conducted for at most 10 years. The identities of the participants will be protected by the use of participant numbers in any analysis conducted or any reporting. Any visuals that will be used in our reports will ensure anonymity (e.g. by blurring faces). All participants are voluntarily participating, ensuring that the participants' guardians are in full knowledge of de research, privacy of data and data storage.

Study contact details for further information:

Purna Bishas, s.a.bishas@student.utwente.nl

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

Consent Form for *neurodiverse sensory preception*

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [DD/MM/YYYY], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
I consent voluntarily for my child to be a participant in this study and understand that they can refuse to answer questions and can withdraw from the study at any time, without having to give a reason.	☐	☐
I consent for my child to be audio-recorded	☐	☐
I consent for my child to be video-recorded	☐	☐
I consent that the recorded audio and video files may be used in the report, with the visuals blurred to ensure the participants' anonymity.	☐	☐
I agree that my children's information can be quoted anonymously in research outputs	☐	☐
Use of the information in the study		
I understand that the information I provide will be used for graduation reports and possible future publications.	☐	☐
I understand that any personal information collected about my child that can identify them, such as [e.g. my name or where I live], will not be shared beyond the study team.	☐	☐
Future use and reuse of the information by others		
I give permission for the anonymised transcripts, audio and video *recording* that I provide to be archived in a secure file on a computer, so it can be used for future research and learning. Afterthe study has been finalized, the files will be destroyed from the database.	☐	☐

Signatures

______________________ ____________________ ________
Name of legal representative Signature Date

____
Name of participant

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_________________________ ___________________ ________
Purna Bishas Signature Date

_________________________ ___________________ ________
Lara Oral Signature Date

_________________________ ___________________ ________
Yifan Cheng Signature Date

Study contact details for further information:

Purna Bishas, s.a.bishas@student.utwente.nl Lara Oral, l.oral@student.utwente.nl

Yifan Cheng, y.cheng-2@student.utwente.nl

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

___/___/______

Informatie brief (NL)

Geachte leraren/verzorgers en ouders,

Nogmaals bedankt voor uw interesse en deelname aan onze studie. Met deze brief hopen wij u beter te informeren over wat de workshop inhoudt en waar uw kinderen aan deelnemen.

Ons doel

Onze intentie is om uw kinderen te laten spelen met elkaar op speelse, bewegelijke manieren. Naast het hebben van plezier dragen ze mee in ons afstuderen, dat gaat over het ontwerpen van technologische systemen. Deze toekomstige ontwerpen hebben als doel om samenwerking te versterken en plezier te hebben voor neurodiverse kinderen in sociale situaties.

Wat houdt de workshop in?

Het onderzoek zal worden gedaan tijdens de speelsessies, wij kijken naar ervaring die de kinderen hebben wanneer zij met de verschillende zintuigen stimulerende objecten gebruiken. (zien, voelen en horen) Wij willen graag ontwerpen wat kinderen nodig hebben met betrekking tot de zintuiglijke waarnemingen. Door deze workshops krijgen wij waardevolle inzichten om voor te ontwerpen voor de zintuiglijke stimulans.

De deelnemers zullen maximaal in 3 workshops deelnemen in de periode vanaf nu tot aan de zomer 2023. De workshops bestaan uit verschillende sessies die ongeveer 10-15 minuten duren. In totaal zal dat maximaal 45 minuten zijn per workshop. Er zijn voldoende pauzes tijdens de workshop en die kinderen zijn vrij om zich te verplaatsen en verwijderen van de spelomgeving. In de workshops zullen de kinderen deelnemen in duo's of trio's. De bewegingssensoren bevinden zich in objecten die de deelnemers kunnen vasthouden, dragen (zoals een armband) of waarnemen(zoals bij schermen).

De deelnemers zijn niet verplicht tot bepaalde handelingen en kunnen zich zonder reden afmelden voor de studie. De objecten hoeven de kinderen niet aan te raken indien niet gewenst. De geluiden die de deelnemers zullen horen worden ook in normaal gehoorbereik en veranderingen zullen worden gemaakt in het geval van ongemak.

Formele toestemming & annuleringsverzoek

Gezien de deelnemende leerling minderjarig is dient het toestemmingsformulier te worden getekend door een ouder en/of de school leraren, dit met de toestemming van de deelnemende leerling om vrijwillig mee te doen met de studie.
In het geval dat de leerling niet meer mee wil doen aan de studie en daarmee zijn/haar deelname wil annuleren kan dat door een van de organisatoren te informeren (Yifan, Lara of

Purna). Dit kan tijdens en na de studie. Als de deelnemer zich alsnog wil terugtrekken nadat de studie is voltooid kan (de ouder/verzorger) dit doen door een mail te sturen naar Purna.

De aard van het onderzoek en mogelijke risico's

Dit onderzoek is in geen enkel opzicht een medisch onderzoek. Deze studie heeft ook niets te maken met medische therapie of andere medische procedures.

De sessies zijn volledig veilig zonder enige risico's voor de deelnemer zijn mentale of fysieke gezondheid. Deze studie is goedgekeurd door de ethische commissie van informatie en computer science van de Universiteit Twente.

Data Privacy & veiligheid

De data wordt bewaard op een laptop voor studie doeleinden. Deze laptop is voorzien van een wachtwoord en is alleen toegankelijk door de onderzoekers. De data zal na de studie worden bewaard op een beveiligde research drive voor uiterlijk 10 jaar. De identiteiten van de deelnemers zullen worden beschermd door genummerd te worden in de verdere analyses of rapportages voor de studie. Beelden in de rapportages zullen anonimiteit waarborgen (door gezichten vervagen). Alle deelnemers doen vrijwillig mee aan de studie en zijn zich bewust van de studie in de details en de privacy van de data en data opslag.

Studie contact details en voor meer informatie:

Purna Bishas, s.a.bishas@student.utwente.nl

Informatie voor contact voor vragen over uw rechten als onderzoeksdeelnemer

Als u vragen heeft over uw rechten als onderzoeksdeelnemer of informatie wilt verkrijgen, vragen wilt stellen of zorgen wilt bespreken over deze studie met iemand anders dan de onderzoeker(s), neem dan contact op met de secretaris van de Ethische Commissie Informatie & Computer Science: ethicscommittee-CIS@utwente.nl

Toestemmingsformulier *neurodiverse zintuiglijke waarneming*

U KRIJGT EEN KOPIE VAN DIT TOESTEMMINGSFORMULIER

Kruis aan wat van toepassing is	**Ja**	**Nee**
Deelname in deze studie		
Ik heb de informatie gelezen en begrepen. Deze brief kan ook aan mij zijn voorgelezen. Ik heb de mogelijkheid gekregen om vragen te stellen over de studie en de antwoorden voldoen tot voldoening.	☐	☐
Ik geef toestemming dat mijn kind vrijwillig meedoet aan de studie en begrijpt dat hij/zij de opdrachten en/of instructies mag weigeren, ook mag hij/zij zich volledig terugtrekken uit de studie zonder enige reden.	☐	☐
Ik geef toestemming voor mijn kind om opgenomen te worden (audio)	☐	☐
Ik geef toestemming voor mijn kind om opgenomen te worden (video)	☐	☐
Ik geef toestemming dat de audio en video bestanden gebruikt mogen worden in de rapportage, deze beelden zullen visueel onherkenbaar zijn voor de privacy van de deelnemer.	☐	☐
Ik geef toestemming dat mijn kind zijn/haar information anoniem gequote mag worden in de rapportages	☐	☐
Gebruik van de informatie in de studie		
Ik begrijp dat de informatie die is verstrekt gebruikt wordt voor afstudeer rapportage en mogelijke toekomstige publicaties.	☐	☐
Ik begrijp dat alle persoonlijke data verzamel van mijn kind wat hem kan identificeren (bijv. naam en leeftijd), zal binnen dit team blijven en niet verder worden gedeeld.	☐	☐
Toekomstig gebruik van de research data voor anderen		
Ik geef toestemming voor geanonimiseerde transcripties, audio en video bestanden die ik beschikbaar stel, te worden gearchiveerd in een beveiligde map op een computer. Zodat deze kunnen worden gebruikt voor toekomstige studies en onderwijs. Na de studie zullen de bestanden worden vernietigd van de database.	☐	☐

Handtekeningen

_____________________   ____________________   ________

Naam van de wettelijke vertegenwoordiger   Handtekening   Datum

____

Naam van de deelnemer

Ik heb zo accuraat mogelijk de informatie voorgelezen van de informatiebrief voor de potentiële deelnemer, naar mijn beste vermogen, de deelnemer geïnformeerd tot waarin hij/zij vrijwillig toestemming voor geeft.

________________________   __________________   ________

Purna Bishas   Handtekening   Datum

________________________   __________________   ________

Lara Oral   Handtekening   Datum

________________________   __________________   ________

Yifan Cheng   Handtekening   Datum

Study contact details en voor verdere informatie:

Purna Bishas, s.a.bishas@student.utwente.nl   Lara Oral, l.oral@student.utwente.nl

Yifan Cheng, y.cheng-2@student.utwente.nl

Informatie voor contact voor vragen over uw rechten als onderzoeksdeelnemer

Als u vragen heeft over uw rechten als onderzoeksdeelnemer of informatie wilt verkrijgen, vragen wilt stellen of zorgen wilt bespreken over deze studie met iemand anders dan de onderzoeker(s), neem dan contact op met de secretaris van de Ethische Commissie Informatie & Computer Science: ethicscommittee-CIS@utwente.nl