Cristina Zaga

The Design of Robothings

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Non-Anthropomorphic and Non-verbal
Robots to Promote Collaboration
through Play

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UNIVERSITY
OF TWENTE

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THE DESIGN OF ROBOTHINGS

Non-Anthropomorphic and Non-Verbal Robots to Promote Children's
Collaboration Through Play

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Non-Anthropomorphic and
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Children's Collaboration Through Play

DISSERTATION

to obtain
the degree of doctor at the University of
Twente,
on the authority of the rector magnificus
prof. dr. ir. A. Veldkamp,
on account of the decision of the Doctorate
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by

Cristina Zaga
Born August 2, 1986
in Novara, Italy

Dedicated to all the children who are denied the right to play because of poverty, stigma, misconceptions and violence.

To my Family.

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"I can only note that the past is beautiful because one never realises an emotion at the time. It expands later, and thus we don't have complete emotions about the present, only about the past." —

Virginia Woolf

*I suggest to listen to **L.E.S Artistes** by Santigold and **This Must Be The Place (Naïve Melody)** by Talking Heads while reading the acknowledgements*

A supposedly fun thing I will never do again ends here (cit. David Foster Wallace). It started a long time ago, in the previous decade, in a previous life, in an earlier body type. 2013. I was in Manhattan, lost and mentally stuck, mooching around a pretentious grocery store in the Bowery. Santigold and Talking Heads tunes were bursting in my headphones, the only solace. The fog in my brain was overwhelming: What to do? Should I continue my (extremely nonlinear) academic trajectory and try to get a double master's degree in Twente, even without money and legacy status? Go back to the industry? Go back to Italy? Fuck no, to do what? Juggling three jobs in the creative, tech scene and barely making it? While these questions were rambling in my head, an epiphany, a moment of being (cit. Virginia Woolf). Like the most improbable Mrs. Dalloway, I draw my resolutions from the most mundane of the events. A package of flour fell from the grocery store cupboard. Incredible havoc of white powdery mess spread all around. Such a mess made me realize. You are a mess too. You fall, you come up. You own it; you try it. Maybe you do not have a legacy or money, but you love studying; you love research. Hell, you even start to love statistics and being hella good at it. Just go. One can't become poorer and more displaced than you are.

And, so I did. I flew to the Netherlands: got a double master cum laude, fell in love with academic research (and a man, cliché), turned my back to the Italian creative scene (touché), and worked with the best teachers there are, children. But, one does not radically change her life and become an academic alone.

I must thank, Khiet, my daily supervisor. Without Khiet, I would not be here writing to you, my reader, plain and simple. She mentored me and fiercely supported my candidacy as a graduate student. Khiet, although my interests drifted away from the disciplines you are an absolute rock-star expert in, you have provided an open-minded mentorship and accepted my design-research direction. You provided constant encouragement and championship. You have been a constant in years of instability. For this, I will always be grateful to you. Similarly, I would not be here writing this thesis if it wasn't for my promotor. Vanessa has been a mother figure and role model to me in the last years. You supported my academic ambitions,

even when they deviated from plans. You helped me fight *'the bears on the road'*, and you cheered with me when publishing at CHI and HRI, even when I was too afraid to submit. You champion me to apply for awards I would have never thought to be eligible for, like the Google Women Techmaker award. You have provided the independence I needed to design impossible studies and robots that do not look like robots. You took me under your wings and motivated me when my body failed me, my family suffered, and fate was just not on my side. You helped me root myself in the CHI and CSCW community (and we had fun traveling in New Zealand, Nyc, Austria) and to become a confident teacher while working together on the Global Work course. At the same time, you favored my inclination to design research and my radical opinions on conducting HRI research. I hope you will remember fondly of our journey together, the ups and downs, the successes and the setbacks. I am sure I will. Manja, you were my daily supervisor before choosing an even more successful and rewarding path for your life. You were pivotal: in less than a year, you helped me build my creative confidence, refine my very Italian writing skills into semi-digestible academic English, and structure an international workshop series while I was an academic noobie. Plus, we became good friends. It saddens me that we had to part ways, but I have always treasured our months together. I hope we will catch-up someday.

To my committee members: I am humbled and honored to have you all as reviewers. Malte, you have welcomed me to the RiG lab at Cornell University. You have given me a fantastic gift: support, mentorship (very insightful walks through the campus discussing grounding, emotions, and HRI communication), and independence. I considered my time in Ithaca as the most productive of my Ph.D. life: I have built a robothing, the one I had in my mind since the beginning, but I could not shape, the one that children wanted. I felt empowered to create a vast network of children associations and run a considerably large study, having little or no contacts in the area, building everything from scratch in one hot summer. It was challenging, high-adrenaline, and rewarding. I felt at home in your lab. I hope we will continue to collaborate in the future; we still have papers to publish! Selma, we have met in a sweltering Finnish summer at the HRI summer school. You struck me as one of the most approachable big names in the HRI field, continually inspiring and open to chat. We met again in New Zealand, Vienna and Portland. My admiration for you grew even more. I always hoped to work with you in the future, and I hope one day we will. Birna, we met at HMI, and since then, we have had the most wonderful conversations. You are a role model for many and certainly for me. I hope to continue our discussions soon; it would be cool to collaborate on responsible agency and further diversity and inclusion in computer science (well, in science in general). Maren, we crossed paths thanks to Squirrel. I have always been fascinated by your work, a true pioneer in the field of robotics. You have been a supportive project partner, curious to explore the intersection of

robotics and design. And, the most fantastic dinner companion, we shared quite a bit of fun throughout the years! Dirk, you have been the best group chair one can expect; I am grateful to have known you and shared insightful conversations with you (and you have been the most insightful guide to Utrecht wonders). Unbeknownst to you, we have many common passions: punk and post-punk, philosophy, post-contemporary art, and gastronomy. It is a shame we did not have the chance to talk more about those passions and research; I hope we will. And last but certainly not least, Mascha. Mascha, I am so thrilled that I will be growing as an assistant professor in your group and continue to work with you at the DesignLab. You have been an incredible mentor at the academic and personal level in the last two years. You have helped me grow immensely in such a short time. I am excited to continue my career under your guidance; I believe the future is bright.

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Vienna. The Google Women Techmaker cohort at Google London, thanks to championing diversity and inclusion and opening up opportunities for me. The DesignLab and HCD group at DPM are my new unique homes. Thank you all for the support and collegiality. My dear colleagues in Delft, TUE and Leiden, Luce, Nazli, Minha, and Eduard, I can't wait to continue our collaboration, and I long for a reunion on a terrace with some Moscato wine. I have to admit that these last few years, I had little LIFE, and the time for friends shrank. Still, my dear friends away from home, Anna and The Magnetic Zeros (you know who you are), Andrea, Sudip, Anej, Riccardo, Vera thank you for the good times, the hugs, and for sharing food (the highest form of love in the Italian social vocabulary). I can't wait to cook for you all soon. My forever friends scattered around the world (can't name you all, but if you read, you know whom I am referring to) and those well-rooted in my hometown (Claudia, Lara, and Jay), I promise I will be more present. It's time to nurture LIFE, too, besides the career.

At the moment, my (lockdown) life and home are with Roelof, the real cuore. The epiphany of 2013 brought me to the academic path but also brought me to my new family. Roelof, you have turned your life upside down to make me happy, and you did immensely. You have supported my insane thirst for knowledge, my curiosity burst, my need to explore, my unpredictable spontaneity, and my academic ambitions. You made sure I had food and water when I decided it was good to work for twenty hours non-stop (and it happened weekly); you have championed all my radical ideas, endured my constant traveling, my never-ending working, my writing, my making video interviews and a five-month absence to do my research in the US. You are a treasure and an exceptional human; you let me fly high with you. I look forward to our life together in our new home (now we even have a fluff, Virginia Woolf, our cat).

But, let me introduce you to my original family, my secret weapon. You see, my reader, you need to know this: I am a glitch in the system; I should not be here writing to you. I was born in a *milieu* that generates mostly blue, sometimes white collars, rarely creatives, even more rarely scholars or policymakers. Let's get it straight, I am Italian, white, cisgender, coming from a labor family. I am very privileged, even without generational wealth or academic legacy status. I was not shepherded to academia; I did not even think I could do it. Certainly not in the exceptionally immobile Italian social society. I am the first to graduate from college in my family. First-time graduates in Italy usually wash away to oblivion pretty fast. But, thanks to my family, I found the spiritual resources for my self-determination. Curiosity, creativity, intelligence flows strong in my family. My grandpa was a self-taught poet, painter, and chef who worked his whole life in an asbestos-infested factory during the day and painted at night and weekends. My grandma was the most curious and avid reader, even if she could barely get through primary school. My other grandma was an exquisite home chef who raised above mundane domesticity with a fierce imagination and

incredible storytelling abilities. My father worked in a cookies factory, but he is a writer and scholar at heart. He stole my books coming back from work to read them at any free moment. You could spot him reciting passages of the *Ulysses* of James Joyce, which I was never even able to finish. My mom, a clerk in a tax-return office, is a mathematics wonder who taught me everything calculus even without attending any college-level class: she longed to go to university, but the economy (and civic society) was brutal in the 70s lead years. My sister is a violin talent who self-published a book while studying at university; She is resiliently navigating the kafkaesque Italian job market with an entrepreneurial attitude. Her star will probably shine even more in the future. Their talent, their support, their example nurture my drive and commitment. A not-so-easy life crushed them, poor health whipped them, and the ever-ridiculously oppressing socio-economical system around them plagued their lives. The hardship they endured was my fuel to avenge them metaphorically. I am not as extraordinary as they are. Still, I am here because, implicitly, they have nurtured my grit, passion, and hassle-attitude. They helped me find the money when money was not there; they accepted my radical vision of life, and they feared for all the things they did not know how to shield me from. This work might feel like a little endeavor to you (and it might very well be negligible, of course). Still, it is an exceptional achievement that brings pride to my family, restoring the karma a tiny bit. It is extraordinary closure of a complicated trajectory, carried out in the last few years with an invisible disability, deforming my body (but refining my intellect even more). This work, for all intent and purposes, is dedicated to my family. I became richer (not in money, but still) and grounded. My moment of being in 2013 brought me to my self-actualization, realizing my full potential.

Still, let's not forget that this book and my story aren't just mines. The children metaphorically wrote this book. The more than three hundred children I met taught me so much. I can never thank them enough for letting me co-design with them, observe them, learn from them. They are genuine researchers and philosophers. We should all know how to play with the world and with life as they do.

We are at the end, my dear reader. I did a supposedly fun thing I will never do again. I finished my Ph.D., and I might add a dr. to my name. I promise to my family and to you all to take my new title of doctor of philosophy very seriously. I believe a doctor must not only produce knowledge but also positively impact and collaborate with society. We, you and me, my reader, will design technology that does not create more issues than it solves but helps us imagine an inclusive and equitable future. We are going to shape a future worth wanting (cit. Shannon Vallor). Join me for more moments of being.

Io non
avrei potuto fare che
un mestiere, un mestiere
solo: il mestiere che ho
scelto, e che faccio, quasi
dall'infanzia. (Le pic-
cole virtù, Natalia
Ginzburg). Gra-
zie a tutti.

SUMMARY

Play is the most critical “*job*” of a child: it is fun, but it also involves learning and training collaboration. The social skills needed to collaborate are the most sought-after socio-emotional competencies for the 21st-century but are often overlooked in educational systems worldwide. Social robotic technology could play a significant role in supporting children’s learning of collaborative skills if designed in a responsible and developmentally appropriate fashion.

In education, social robots successfully leverage their ability to communicate socially to support children’s learning. However, by replicating school formats and activities, tutoring robots might bring more challenges than solutions. Researchers in Human-Robot Interaction and Child-Robot Interaction are increasingly exploring new pedagogical paradigms for social robots for children, focusing on play rather than tutoring. What if the technology we design for children could nurture the social skills of children through play? What if the toys children play with could support children’s collaboration through play in a developmentally appropriate way?

This dissertation motivates, theorizes, operationalizes, and evaluates the design space of toys endowed with social robotic technology to support children’s collaboration in play. We define these social robots as *robothings*. The term *robothing* derives from the term *robot* and the term *thing*. The prefix ‘*robo*’ is an abbreviation of the word *robot*. It indicates an autonomous artificial agent that is embodied and communicates. The suffix *thing* is related to the word ‘*thing*’, but it connects with the concept of things developed by the philosopher Bruno Latour [215]. For Latour, everyday objects are not inanimate, nor are simple tools. Objects shape how we perform actions (e.g., a crutch changes the way we walk and experience moving in the space); they extend our capabilities (e.g., the microscope extends our vision capabilities and our knowledge about nature), shaping how we make sense of ourselves and the world, supporting and influencing how people act and make sense of the world. Thus, conceptually *robothings* refer to things as a robotic mediator of the children-world relationship. Concretely, *robothings* are hybrids between objects and social robots. *Robothings* are low/non-anthropomorphic robots that communicate their prosocial intentions to influence people’s behaviors, leveraging their nonverbal communication affordances. We conceptualize the role of a *robothing* as an interactive ‘*thing*’, with its agency, rather than a human-like partner (e.g., teacher, friend) that aims at a human-like agency. Two facets are central in designing *robothings* to promote collaboration among children in play. The first facet is the operationalization of the *robothing*’s intervention and the effects on children’s collaboration of such an intervention. The

second facet is the design of effective robothings' communication relying solely on non-anthropomorphic affordances and nonverbal communication. As a result, the dissertation has two overarching aims: To investigate how robots that have less human-like form and behaviors can promote children's (7-11 years old) collaboration through play, and to probe the design space of non-anthropomorphic nonverbal social communication in child-robot interaction.

We crystallize intervention and communication dynamics of a robothing in collaborative play in a conceptual framework derived from multidisciplinary literature. At the intervention level, a robothing supports collaboration by promoting prosocial behavior by behaving prosocially in collaborative play. To this end, a robothing communicates its prosocial intention in 'human terms'. Communicating in human terms means leveraging the human tendency of parsing contingent movement as intentional. Drawing from the conceptual framework and a behavioral observation study of children, we explored how to design child-robothing communication in collaborative play and evaluated its effects. First, we translated the framework into actionable design principles and guidelines. We then carry out three studies to evaluate robothings' behaviors in existing low or non-anthropomorphic platforms. We learn that a robothing legibly communicates its intention only with minimal gaze movements and actions delivered with a robothing locomotion. We gather first indications that a robothing influences children's social motives to collaborate and reciprocate in collaborative play. However, we observe discrepancies between children's behavioral reactions and their explanation of both their own and the robothing behavior. Therefore, we explore methods to involve children in the design of a robothing's behavior. We introduce a co-design method: PERSpective-taking in Embodied Role-Play (PeerPlay), consisting of two activities Exploratory PeerPlay and Behavior-Authoring Peer Play. The method centers on embodied enactment and perspective-taking to co-design and co-generate robothings behavior in the design process. We describe two workshops with children in which we evaluate the two activities of the methods. We translate the insights from the co-design workshop into an ad-hoc proof-of-concept robothing platform. Based on children's designs, we develop a remotely controlled robothing, Push-one, along with its actions and interaction. We evaluate Push-one's behaviors in a video-based study and a behavioral study.

The dissertation's findings show that by delivering prosocial behavior interventions via actions in play, robothings can impact children's prosocial behavior and reciprocity, thereby promoting collaboration. Simultaneously, the dissertation's methodological exploration shows that designing for children demands focusing on what is meaningful for children and attuning how children develop. The research is a promising step towards the toys and the technology of the future. Toys and technology that enable learning through play giving agency to the child. Toys and technology for a future designed for and with children.

Spelen is de meest kritische “*baan*” van een kind: het is leuk, maar het omvat ook leren en samenwerken. De sociale vaardigheden die nodig zijn om samen te werken, zijn de meest gewilde sociaal-emotionele competenties voor de 21e eeuw, maar worden vaak over het hoofd gezien in onderwijssystemen over de hele wereld. Sociale robottechnologie zou een belangrijke rol kunnen spelen bij het ondersteunen van het leren van samenwerkingsvaardigheden door kinderen als ze op een verantwoorde en ontwikkelingsgeschikte manier worden ontworpen.

In het onderwijs gebruiken sociale robots met succes hun vermogen om sociaal te communiceren om het leren van kinderen te ondersteunen. Door schoolformats en -activiteiten te repliceren, kan bijles van robots echter meer uitdagingen dan oplossingen met zich meebrengen. Onderzoekers op het gebied van mens-robot interactie en kind-robot interactie onderzoeken steeds vaker nieuwe pedagogische paradigma’s voor sociale robots voor kinderen, waarbij ze zich richten op spelen in plaats van bijles. Wat als de technologie die we voor kinderen ontwerpen, de sociale vaardigheden van kinderen door middel van spel zou kunnen stimuleren? Wat als het speelgoed waarmee kinderen spelen de samenwerking van kinderen zou kunnen ondersteunen door te spelen op een ontwikkelingsgeschikte manier?

Dit proefschrift motiveert, theoretiseert, operationaliseert en evalueert de ontwerpruimte van speelgoed dat is uitgerust met sociale robottechnologie om de samenwerking van kinderen bij het spelen te ondersteunen. We definiëren deze sociale robots als *robothings*. De term *robothing* is afgeleid van de term *robot* en de term *ding*. Het voorvoegsel ‘*robo*’ is een afkorting van het woord *robot*. Het geeft een autonome kunstmatige agent aan die is belichaamd en communiceert. Het achtervoegsel *ding* is gerelateerd aan het woord ‘*ding*’, maar het sluit aan bij het concept van dingen ontwikkeld door de filosoof Bruno Latour [215]. Voor Latour zijn alledaagse voorwerpen niet levenloos, evenmin als eenvoudige gereedschappen. Objecten bepalen hoe we acties uitvoeren (bijv. een kruk verandert de manier waarop we lopen); ze vergroten onze capaciteiten (bijv. de microscoop vergroot onze zichtmogelijkheden), ze geven vorm aan hoe we onszelf en de wereld begrijpen, ondersteunen en beïnvloeden hoe mensen handelen en de wereld begrijpen. Conceptueel verwijzen *robothings* dus naar dingen als een robotbemiddelaar in de relatie tussen kinderen en wereld. Concreet zijn *robothings* hybriden tussen objecten en sociale robots. *Robthings* zijn lage / niet-antropomorfe robots die hun prosociale bedoelingen communiceren om het gedrag van mensen te beïnvloeden, door gebruik te maken van hun non-verbale communicatiemogelijkheden. We conceptualiseren de rol van een *robothandeling* als een interactief ‘*ding*’, met zijn autonomie, in plaats van een mensachtige

partner (bijv. leraar, vriend) die gericht is op een mensachtige autonomie. Bij het ontwerpen van robothings staan twee facetten centraal om de samenwerking tussen spelende kinderen te bevorderen. Het eerste facet is de operationalisering van de interventie van de robothing en de effecten van een dergelijke interventie op de medewerking van kinderen. Het tweede facet is het ontwerp van effectieve robothing-communicatie die uitsluitend berust op niet-antropomorfe mogelijkheden en non-verbale communicatie. Als gevolg hiervan heeft het proefschrift twee overkoepelende doelen: onderzoeken hoe robots met een minder mensachtige vorm en gedrag de samenwerking tussen kinderen (7-11 jaar) kunnen bevorderen door middel van spel, en de ontwerpruimte onderzoeken van niet-antropomorfe non-verbale sociale communicatie in de interactie tussen kind en robot.

We kristalliseren de interventie- en communicatiedynamiek van een robothing in ‘collaborative play’ in een conceptueel raamwerk afgeleid van multidisciplinaire literatuur. Op interventieniveau ondersteunt een robothing de samenwerking door prosociaal gedrag te bevorderen door zich prosociaal te gedragen in samenwerkend spel. Daartoe communiceert een robothing zijn prosociale intentie in ‘menselijke termen’. Communiceren in menselijke termen betekent het benutten van de menselijke neiging om contingente bewegingen als opzettelijk te parseren. Op basis van het conceptuele raamwerk en een gedragsobservatiestudie van kinderen, hebben we onderzocht hoe we communicatie tussen kinderen kunnen ontwerpen in collaborative play en de effecten ervan geëvalueerd. Ten eerste hebben we het raamwerk vertaald in uitvoerbare ontwerpprincipes en richtlijnen. Vervolgens voeren we drie onderzoeken uit om het gedrag van robothings in bestaande laag of niet-antropomorfe platforms te evalueren. We leren dat een robothandeling zijn bedoeling leesbaar communiceert met slechts minimale blikbewegingen en acties die worden geleverd met een robothandeling. We verzamelen de eerste indicaties dat een robothing de sociale motieven van kinderen beïnvloedt om samen te werken en wederkerig te spelen in samenspel. We zien echter discrepanties tussen de gedragsreacties van kinderen en hun verklaring van zowel hun eigen gedrag als het robothing gedrag.

Daarom onderzoeken we methoden om kinderen te betrekken bij het ontwerp van het gedrag van een robothing. We introduceren een co-design-methode: PERSpectief nemen in Embodied Rollenspel (PeerPlay), bestaande uit twee activiteiten: Exploratory PeerPlay en Behaviour-Authoring Peer Play. De methode concentreert zich op belichaamde enactment en het nemen van perspectief om het gedrag van robothings in het ontwerpproces mede te ontwerpen en te genereren. We beschrijven twee workshops met kinderen waarin we de twee activiteiten van de methoden evalueren.

We vertalen de inzichten uit de co-design workshop naar een ad-hoc proof-of-concept robothing platform. Op basis van kinderontwerpen ontwikkelen we een op afstand bedienbare robothing, Push-one, samen met

zijn acties en interactie. We evalueren het gedrag van Push-one in een videostudie en een gedragsstudie.

De bevindingen van het proefschrift laten zien dat robothings, door het leveren van prosociale gedragsinterventies via spelacties, het prosociaal gedrag en de wederkerigheid van kinderen kunnen beïnvloeden, waardoor samenwerking wordt bevorderd. Tegelijkertijd laat de methodologische verkenning van het proefschrift zien dat ontwerpen voor kinderen om aandacht vraagt voor wat betekenisvol is voor kinderen en voor het afstemmen van hoe kinderen zich ontwikkelen. Het onderzoek is een veelbelovende stap op weg naar het speelgoed en de technologie van de toekomst. Speelgoed en technologie die spelenderwijs leren mogelijk maken en het kind autonomie geven. Speelgoed en technologie voor een toekomst ontworpen voor en met kinderen.

CONTENTS

1	INTRODUCTION	3
1.1	Motivation, Opportunities and Challenges	5
1.1.1	Going Beyond the Social Robotics Status Quo: Designing Robothings for Children	5
1.1.2	Intervening in Collaboration between Children: Exploring Playful Interventions	7
1.1.3	Human-like Communication vs. Communicating in ‘Human terms’: The Challenges of Designing Robothings’ Communication	9
1.1.4	Design for and Designing with Children: Involving Children in the Design Process	11
1.2	Aim and Research Questions	12
1.3	Research Approach and Methods	15
1.3.1	Methods	15
1.4	Structure and Outline of the Dissertation	16
1.4.1	Part i. The ABCs of Designing Robothings to Promote Children’s Collaboration Through Play.	18
1.4.2	Part ii. Design and Evaluation of a Robothing to Promote Children’s Collaboration through Play	22
I	THE ABCS OF DESIGNING ROBOTHINGS TO PROMOTE CHILDREN’S COLLABORATION THROUGH PLAY	
2	THEORY, RELATED WORK AND CONCEPTUAL FRAMEWORK	27
2.1	Chapter Introduction	28
2.2	Social Robots for Children	29
2.2.1	What are Social Robots?	30
2.2.2	Social Robots for Children: Interaction Paradigms	31
2.2.3	Social Robots for Children: Form and Behaviors	36
2.2.4	The Role of Children’s Expectations	37
2.2.5	Social Robots for Children: Conclusions	40
2.2.6	Collaboration in Humans and Children	41
2.2.7	Prosocial Behaviors in Collaborative Play	45
2.2.8	Children’s Conflict in Collaborative play	48
2.2.9	Play in Childhood	51
2.2.10	Collaborative Play in Childhood	54
2.2.11	Children’s Collaboration, Prosocial Behavior and Collaborative Play: Conclusions	55
2.3	Related Work: Technology for Children’s Collaborative Play	56
2.3.1	School Based and Playful Interventions	56
2.3.2	Computer Interventions for Collaborative Play	59
2.3.3	Child-Robot Interventions for Collaborative Play	61

2.3.4	Related work: Conclusions	62
2.4	Designing Social Robot Communication	62
2.4.1	Designing for Human-like Communication	63
2.4.2	Designing Communication in Human Terms	64
2.4.3	Designing Social Robot Communication Approaches	66
2.4.4	Designing Social Robot Communication: Conclusions	68
2.5	Conceptual Framework	68
2.5.1	Intervening in Collaboration Between Children: Exploring Playful Interventions	69
2.5.2	Beyond the Social Robot Status Quo: Communicating in Human Terms	70
2.5.3	Robothings	72
2.6	Chapter Conclusions	73
3	BEHAVIORAL OBSERVATION STUDY OF CHILDREN'S COLLABORATIVE PLAY AND SCENARIOS	75
3.1	Chapter Introduction	76
3.2	Study 1: Behavioral Observation of Children Collaborative Play	77
3.2.1	Related Work and Research Questions	77
3.2.2	Methods	80
3.2.3	Data Analysis	82
3.2.4	Findings	86
3.2.5	Discussion of the Findings	92
3.2.6	Study 1: Conclusions	96
3.3	Scenarios	97
3.3.1	Elements of the Scenarios	97
3.3.2	Written Scenarios	99
3.4	Chapter Conclusions	100
4	ROBOTHING BEHAVIOR AND INTERACTION DESIGN	101
4.1	Chapter Introduction	102
4.2	Study 2: Children's Understanding of Minimal Robothing's Gaze-Movements	104
4.2.1	Introduction	104
4.2.2	Related Work in HRI and cHRI	106
4.2.3	Methods	108
4.2.4	Results	112
4.2.5	Perception of Helpfulness	113
4.2.6	Discussion	113
4.2.7	Conclusions Study 2	116
4.3	Study 3: Exploring Sound to Communicate a Robothing's Help-giving	117
4.3.1	Introduction	117
4.3.2	Related Work	119
4.3.3	Methods	120
4.3.4	Results	123

4.3.5	Discussion	125
4.3.6	Conclusions Study 3	128
4.4	Study 4: Exploring a Robothing's Influence on Children's Reciprocity	130
4.4.1	Introduction	130
4.4.2	Background and Related Work	132
4.4.3	Methods	134
4.4.4	Setup and Procedure	140
4.4.5	Measures	141
4.4.6	Findings	144
4.4.7	Tendency to help	148
4.4.8	Discussion	150
4.4.9	Study 4: Conclusions	153
4.5	Chapter Conclusions	153
5	A METHOD TO DESIGN ROBOTHINGS BEHAVIORS WITH CHILDREN	157
5.1	Chapter Introduction	158
5.1.1	Theory and Related Work	161
5.1.2	Perspective Taking in Embodied Role Play	167
5.1.3	PeerPlay: Dimensions and Characteristics	169
5.1.4	A method to Co-design Robot's Behavior with Children: Conclusions	173
5.2	Workshop 1: Exploratory PeerPlay	174
5.2.1	Workshop Method	174
5.2.2	Findings	184
5.2.3	Discussion	188
5.2.4	What Reflections Exploratory PeerPlay Yield in Children?	190
5.2.5	Exploratory PeerPlay Workshop: Conclusions	192
5.3	Workshop 2: Behavior Authoring PeerPlay	193
5.3.1	Pilot to Define the Behavior Authoring Operationalization	193
5.3.2	Workshop Method	195
5.3.3	Findings	198
5.3.4	Discussion	199
5.3.5	Behavior Authoring PeerPlay Workshop: Conclusions	201
5.4	Chapter conclusion	202
II	DESIGN AND EVALUATION OF A ROBOTHING TO PROMOTE CHILDREN'S COLLABORATION THROUGH PLAY	
6	PUSH-ONE: NON-ANTHROPOMORPHIC AND NON-VERBAL ROBOT TO PROMOTE CHILDREN'S COLLABORATION THROUGH PLAY	209
6.1	Chapter Introduction	211
6.2	Design Vision, Principles, Approach and Process	212
6.2.1	Design Vision	212

6.2.2	Design Approach	212
6.2.3	Design Process	213
6.2.4	Revised Design Principles and Guidelines	214
6.3	From Movements to Behaviors	215
6.3.1	Outcomes of the Co-design Workshops with Children	216
6.3.2	Selecting Motion Elements	218
6.3.3	Exploring the Selected Motion Elements	219
6.3.4	Visually Representing the Motion Elements	221
6.3.5	Robothing's Behaviors: Distilling Actions and Motion-Styles	222
6.3.6	From Movement to Behaviors: Conclusions	223
6.4	From Behaviors to Form	223
6.4.1	Giving Shape to Actions and Motion Styles: Selecting The Type of Drive	223
6.4.2	Distilling Technology Requirements	225
6.4.3	First prototype: Hardware and Software	227
6.4.4	First prototype: Implementing the Robothing's Behaviors	229
6.4.5	Exploring a Robothing Form: Design Metaphor, Sketches and Prototyping	230
6.4.6	Technical Tests and Second Prototype	233
6.4.7	From Behaviors to Form: Conclusions	237
6.5	Interaction Design	237
6.5.1	Child-Robothing Interaction	237
6.5.2	Scenarios	239
6.5.3	Interaction Design: Conclusions	243
6.6	Playtests and Final Design	243
6.6.1	Play-Tests	244
6.6.2	Final Design	246
6.7	Reflections and Lessons Learned	246
6.7.1	Reflections on the Design Process	247
6.7.2	Reflections on the Design Outcomes	248
6.7.3	Lessons Learned from the Play-Tests	249
6.7.4	General Implications	250
6.7.5	Limitations	250
6.8	Chapter Conclusions	251
7	COMMUNICATING CONFLICT-RESOLUTION INTENTIONS IN A ROBOTING USING LOCOMOTION: THE INTERPLAY OF ACTIONS AND MOTION STYLES	253
7.1	Chapter Introduction	254
7.2	Study 5. How children understand and perceive a robothing's behavior to intervene in conflicts: the interplay of robothing actions and motion styles	255
7.2.1	Introduction	255
7.2.2	Background and Related Work	256

7.2.3	Methods	259
7.2.4	Data Analysis	269
7.2.5	Findings and Results	273
7.2.6	Discussion	286
7.2.7	Study 5: Conclusions	289
7.3	Chapter Conclusions	291
8	WHEN A ROBOTING IS PROSOCIAL IN A CONFLICT OR COER- SIVE: EFFECT ON CHILDREN'S PROSOCIAL BEHAVIORS AND PERCEPTION OF COLLABORATION	293
8.1	Chapter Introduction	294
8.2	Study 6: The Effects of a Robothing Conflict Resolution Strat- egy on Children's Prosocial Behaviors and Perception of Col- laboration	296
8.3	Related Work: Robot's Impact on Conflict Resolution and Collaboration	298
8.4	Methods	299
8.4.1	Participants	299
8.4.2	Ethics	300
8.4.3	Set-up and Study Protocol	304
8.4.4	Measures	305
8.4.5	Data Analysis	307
8.5	Results	311
8.5.1	Perception of Helpfulness of the Robothing (H1a)	311
8.5.2	Perception of Helpfulness of the other Child (H2a)	314
8.5.3	Perceived Collaboration with the Robothing (H1b)	315
8.5.4	Perceived Collaboration with the other Child (H2b)	316
8.5.5	Behavioral Observation: Prosocial Behaviors after the Intervention (H3a)	316
8.5.6	Help test (H3b)	317
8.5.7	Share test (H3a, H3b)	318
8.5.8	Discussion	318
8.5.9	Study 6: Conclusions	322
8.6	Chapter Conclusions	322
9	DISCUSSION AND CONCLUSION	325
9.1	Overview of the findings	326
9.1.1	RQ1.How do children regulate prosocial behaviors to collaborate in play?	327
9.1.2	RQ2. How Should the Interaction with a Robothing be Designed to Impact Prosocial Dynamics in Play?	328
9.1.3	RQ3.How Should the Non-verbal Behavior of Low/non- anthropomorphic Robots Be Designed to Communi- cate a Robot's Intention to Children?	330
9.1.4	RQ4. How Do Children Interpret and Perceive the Non-verbal Behavior of Low/non-anthropomorphic Robots in Play?	333

CONTENTS

9.1.5	RQ5. What Method is Suitable to Co-Design the Non-verbal Behavior of a Robot with Children?	334
9.1.6	RQ6. What are the Effects of a Robothing Behavior on the Prosocial Behavior and Collaboration of Children in Play?	337
9.1.7	Conclusions: The ABCs of Robothings	340
9.2	Implications	341
9.3	Limitations	342
9.3.1	Robothings are not Autonomous Agents (yet)	343
9.3.2	Generalizability of the Findings and Behavior Design	344
9.3.3	Ecological, Internal, Face Validity	344
9.3.4	Ethics and Moral Implications	346
9.4	Future Work	346
9.4.1	Towards a Theory of Robots Communicating in Human-Terms	347
9.4.2	Studying the Interplay of a Robothing Appearance and Behaviors	347
9.4.3	Robothings in Other Domains	348
9.4.4	Making Robothings Autonomous	348
9.4.5	Co-design Explainable Robothing Behaviors	349
9.4.6	Responsible Child-Robot Interaction	349
9.5	Contributions	351
9.6	Concluding remarks	353
A	APPENDIX	355
A.1	Chapter 4	355
A.1.1	Study 4: SDQ questionnaire in English	355
A.2	Chapter 7	356
A.2.1	Code for Push-one Behaviors	356
A.3	Chapter 8	360
A.3.1	Study 5: Empathy Index	360
	BIBLIOGRAPHY	369

LIST OF FIGURES

- Figure 1 In the figure, a visualization inspired by Druin’s taxonomy of children’s involvement in the development of technology [88] and van Doorn’s one [82]. The figure is showing the roles children take in the design process. We highlight the role of informant, as children take this role in Chapter 5 to co-design robothings’ behaviors. 17
- Figure 2 In the figure, a reproduction of a figure by Bont et al. [35]. The figure shows the level of involvement of people in the design process and maps the methods we use in the dissertation into the various levels. 17
- Figure 3 In the figure, the robot platforms which we used to explore the design space of robothings. We worked with four different robots. In the figure, we detail whether the robot is (i) low or non-anthropomorphic, (ii) whether the robot is autonomous or remote-controlled, (iii) the primary interaction modality, and (iv) whether the robot is commercial or developed in research settings. 18
- Figure 4 The figure is visualizing the structure of the dissertation. The visualization is using the metaphor of primary shapes to break down the flow of the dissertation. On top, the initial situation. Chapter 1, the Introduction, poses fundamental questions. The dissertation goes through two cycles to answer the research questions. Part i explores the foundations of the design of Robothings, the ‘ABCs’. Chapters in Part i constitute a unity of sort, represented by the circle shape. Part I informs, guides, grounds a subsequent research cycle. Part ii is a process from design to evaluation of a Robothing to promote children’s collaboration. Both parts contribute to answering the research questions, discussed in Chapter 9 21
- Figure 5 The figure is illustrating two examples of tutoring interaction paradigms. On the left a) the work of [413] comparing peer to tutor roles in cHRI. On the right b) a picture from the Enigma project, exploring a robot peer as a near-future tool for autism education [307]. 31

LIST OF FIGURES

- Figure 6 The figure is illustrating two examples of playful interaction paradigms. On the left a) the work of [235] By playing with the robot Shybo, children could explore concepts related to various subjects. On the right b) the Squirrel project developed a robot to playfully tidy-up with children. 32
- Figure 7 The infographic is illustrating how the socio-emotional level of collaboration influences the cognitive level of collaboration, that is the processes to coordinate intentions of doing something together, and the behavioral level of collaboration, that is the observable behaviors in collaboration. 41
- Figure 8 The diagram is summarizing our conceptual framework. 70
- Figure 9 The figure is exemplifying what it means to communicate in ‘human terms’. A ball suddenly starts to move autonomously towards a person without being pushed by anybody. The ball directs itself towards the person, rolls towards the person, and pushes a box with it while rolling. Then, the ball stops in front of the person. Why is the ball doing this? We can infer the ball’s intention from its actions: It looks like the ball wants us to have the box. 71
- Figure 10 The Figure is visualizing our design principles. 72
- Figure 11 The figure shows the materials we used in the observational studies. In a), the magnetic blocks (Tegu) and an example of construction. In b), the pictures children replicated and in c) a child taking blocks from his/her bucket. 81
- Figure 12 In the figure, the set-up of the observational study. Three children cluster around a given area where to build a construction. The picture is taken from the audio-video recordings. 83
- Figure 13 The figure is a schematic representation of the observational study setup illustrating the positions children took during collaborative play. We identified seven areas where children sat during the tasks. 86
- Figure 14 Examples of goal-oriented behaviors taken from the video recordings. 87
- Figure 15 Example of sharing behaviors taken from the video recordings. 87
- Figure 16 Example of aggressive behaviors taken from the video recordings. 89

Figure 17	The figure describe the steps we take in the design's process of Part I, and hones-in the structure of Chapter 4. 103
Figure 18	Figure a) the robot and the actor at the beginning of the playful sorting task; b) the robot exhibiting social-gaze movement towards the actor; c) the robot exhibiting deictic-gaze movement to provide helpful referential information. 109
Figure 19	The interaction effect of social and deictic-gaze movements on perceived animacy of the robot. Error bars are standard deviations. 113
Figure 20	The main effects of social-gaze movements on perceived likeability of the robot. Error Bars are standard deviations. 114
Figure 21	Main effects of social and deictic-gaze movements on perceived helpfulness of the robot. Error bars are standard deviations. 114
Figure 22	A screenshot from the data collected. In the picture, two participants playing with the robot the tangible 4x4 pair-matching memory game. 124
Figure 23	The figure shows in a) one of the participants compiling responding to our ex-post recognition test. Figure b) shows the four cartoon-like images depicting the intentions of the sounds (i.e., suggestion, doubt, error, reward). 124
Figure 24	The graph shows the results of the rate of compliance per round. Compliance was significantly higher in the NS condition than in the NS and GS condition ($F(2, 15) = 8.152, p = .004$). Error bars show the 95% confidence interval. 126
Figure 25	The graph shows the results of the average time per round. Rounds were significantly quicker in the NS condition than in the NS (($F(2, 15) = 4.202, p = .036$), but no difference were found between NS and GS. Error bars show the 95% confidence interval. 126
Figure 26	Figure taken from [264] to illustrate direct and indirect reciprocity. Top shows direct reciprocity. Bottom shows indirect reciprocity, divided into upstream (left) and downstream (right). 133
Figure 27	The figure illustrates the case-study sessions. 134
Figure 28	A sample of questions from the personality test developed by [238] as administrated to the children 136
Figure 29	Results personality traits for C1, C2,C3, the children in the cohort 137

LIST OF FIGURES

- Figure 30 In the figure a rendering of the Squirrel Robot, the robothing we examined in this case-study. 138
- Figure 31 In the figure a visual representation of the robothing's behaviors in the case-study. On the left the social gaze-movements (as designed in Study 2). On the right the sharing behavior and taking away behaviors: The robothing "pushed" by driving (locomotion) a relevant object either in the direction of one of the children (to share the object) or away from the children (to take away the object). To participate in the game the robot used a similar behavior to push the object in the "dispatch area" in the center. 138
- Figure 32 The figure is a screenshot from the recordings. The figure describes the setup of the case-study. 140
- Figure 33 The figures present the direct and indirect reciprocity findings for the two sharing sessions and for the taking session. The arrows indicate the direction of the reciprocal sharing behavior. Next to the arrow, the type (D means direct, ID indirect) and number of reciprocity acts counted. 146
- Figure 34 The figure presents an info-graphic to summarize the results of the direct reciprocity in the forced choice help-test. Results are provided per child and per session. 148
- Figure 35 In the figure, a visualization adapted from the Convivial Toolbox by E. Sanders, P.J. Stappers [348] to be applied in cHRI. The Figure visualizes what type of knowledge co-design is able to bring to the surface. 168
- Figure 36 In the figure, a visualization of the PeerPlay method projected on the design process phases. 173
- Figure 37 In the figure a representation of how we operationalized the Exploratory PeerPlay activity in the workshop. 175
- Figure 38 In the Figure, we detail the materials of the Exploratory PeerPlay Workshop. 177
- Figure 39 In the Figure, children engaged in Exploratory PeerPlay. Particularly, we show the Role-Play with the puppet exercise in which children puppettered the robot non-verbal behaviors, and the Refection exercise in which children took perspective and explained each other designs. 177

- Figure 40 In the Figure, children engaged in Exploratory Peer-Play. Particularly, we show the role-play with the body exercise in which children enacted the given scenario using their body to set the perspective taking mindset and the role-play with puppet exercise in which children enacted the behaviors with a puppet in a scenario. 178
- Figure 41 In the figure, on the left the tangible behavior authoring operationalization featuring the physical device bearing similarities with the robot platform. On the right, the GUI based operationalization. 194
- Figure 42 In the figure, the Behavior Authoring operationalization in the workshop. 196
- Figure 43 In the figure, children participating in the behavior authoring workshop. On the left, a child co-designer role-play, enabled by kinaesthetic imitation. On the right, a child observing the role-play and making sense of the narrative. 197
- Figure 44 We re-proposed the conceptual framework introduced in Chapter 2 as a reference for the reader. 214
- Figure 45 The figure shows the seven design principles introduced in Chapter 2 and the 2 additional principles regarding the form and embodiment of a robothing. 216
- Figure 46 The figure visualizes the design process to develop Push-one, a proof-of-concept robothing. As such, the figure refers to the design process of Chapter 6 and its connection with the methods/research of the preceding and following chapters. For an overview of the dissertation's approach and methods, please refer to Chapter 1. 217
- Figure 47 The figure shows the first prototype we assembled together with its parts. The prototype has low-cost accessible holonomic hardware from a customizable do-it-yourself omnidirectional wheel chassis kit by Wicked Device LCC. 227
- Figure 48 The figure shows the twenty images of products, toys and robots we selected to get inspiration for the design metaphors. The images are systematized in Cartesian quadrants. The x axis go from abstract to concrete embodiment, the y axis from non-anthropomorphic to anthropomorphic embodiment. 231
- Figure 49 In the figure, two dimensional and tridimensional sketches of the outer-shell appearance. 232

LIST OF FIGURES

Figure 50	In the figure, the final tridimensional sketch of robothing's surface appereance. 232
Figure 51	In the figure, the 3D model of the body covering the holonomic platform, hence the outer shape of our robothing prototype. The casing on the holonomic platform is visible below the outer shape, blue in the figure. 233
Figure 52	In the figure, the 3D model of casing of the honolomic platform. 234
Figure 53	In the figure, the 3D model of the shovel of the robothing. 234
Figure 54	In the figure, the 3D model of the additional outer disc of the holonomic platform casing. 235
Figure 55	In the figure, a picture from the technical test of the first prototype 236
Figure 56	In the figure, a view of the internal casing of the robothing prototype, the hardware and wheels. 236
Figure 57	The figure shows a drawing of the envisioned scenario. Two children are engaged in a Tangram puzzle game with the robothing. 240
Figure 58	The figure shows a drawing of the envisioned dynamics in the scenario as well as the robothing's actions. 242
Figure 59	The figure shows a picture from one of the play-tests sessions with adults 244
Figure 60	In the figure, the final version of the Push-one, a robothing for collaborative play 247
Figure 61	The Push-one robot, the robothing of the VHRI study, with tangram puzzle. 259
Figure 62	Details of the within-subject conditions and between-subjects conditions of the VHRI study. The pictures visualize the motion styles. 262
Figure 63	The pictures show frames from the videos stimuli. Figure a) shows the giving action, figure b) the taking action, figure c) the not intervening action 262
Figure 64	The Scenario of the Video-Based HRI Study 263
Figure 65	A frame from the conflict scene in the video stimuli. 263
Figure 66	The figure depicts the interaction effect between the action of the robot (giving or not intervening or taking) and the style of the action (linear, sine-wave, jerky) on the perceived helpfulness of the robot. 277
Figure 67	The figure depicts the interaction effect between the style of the action and the actions of the robothing on the perceived helpfulness of the robot. 278

- Figure 68 The figure illustrates the conditions of Study 6. The figure provides details about the way conditions were operationalized. 301
- Figure 69 The figure details the sequences of actions after the conflict is elicited. The pictures show the giving condition. 302
- Figure 70 The figure illustrates the puzzle outline presented to the children. 303
- Figure 71 The strategy of the robothing (prosocial or coercive) and the action of the child (taking or not taking the last available piece) on the perceived helpfulness of the robot compared pre- and post- measurements 311
- Figure 72 The simple main effect of the strategy of the robothing (prosocial or coercive) on the perceived helpfulness of the robot compared pre- and post-measurements 312
- Figure 73 The strategy of the robothing (prosocial or coercive) and the action of the child (taking or not taking the last available piece) on the perceived helpfulness of the other child compared pre- and post- measurements 313
- Figure 74 The simple main effect of the strategy of the robothing (prosocial or coercive) on the perceived helpfulness of the other child compared pre- and post-measurements 313
- Figure 75 The simple main effect of the action of the child during conflict elicitation (taking the last piece or not taking the last piece) on the perceived helpfulness of the other child compared pre- and post-measurements 314
- Figure 76 The figure is visualizing the conceptual framework that guide the dissertation. The visualization shows the intervention level with the high level interaction and the communication level with the communication. 329

LIST OF FIGURES

LIST OF TABLES

Table 1	The table is summarizing the studies reported in the dissertation. The first column describes the study and indicates where is the study reported. The following three columns briefly summarize each study's research design, indicating the robot, methods, and participants of the study. 22
Table 2	The table is showing the many forms play could take: on the left types of play, on the right the activities related the type of play. Types of play are to be understood in a spectrum, often overlapping one with the other. 51
Table 3	The table details the coding scheme of social behaviors we used to annotate children's behavior. As explained, we have first identified 21 physical behaviors children exhibited in the study (column examples of behavior). Then, we have cluster those behaviors in higher-level categories (column code). 83
Table 4	The table details the coding scheme of prosocial and conflict sequences. 86
Table 5	Counts and percentages of goal-directed, sharing, aggressive, referential attention and observing behaviors annotated in the study. Results are reported per task, per group and per child in the task. C1 s-tands for child 1, C2 stands for child 2, C3 stands for child 3. 88
Table 6	Counts and percentages of the sequences of actions 89
Table 7	The table illustrates the results of the position annotations. For each of the three collaborative play tasks, we detail which position the children have taken (we do not divide all the children per group). Column one refers to the position taken by all the children assigned to C1 positions, column two refers to the positions taken by all the children assigned to C2 positions, column three refers to the positions taken by all the children assigned to C3 positions. 90
Table 8	Number and percentage of overlap between dyads (C1/C2, C2/C3, C1/C3) and triad (C1/C2/C3) per group per task. 91

Table 9	The table summarizes the prototype of robothings behaviors designed according to our framework. For each behavior modalities and design is detailed. 102
Table 10	The table illustrates the Animacy, Likeability and Helpfulness items. Animacy and Likeability items are taken from the Godspeed questionnaire, a 5-point semantic scale. The Helpfulness item is a 5-point Likert scale item, presented to the children with 5 smileys instead of numbers. We used the validated instrument Smiley-o-meter [288, 243]. 110
Table 11	The cohort demographics and prior experience with robots. C1, C2, C3 are abbreviations that indicate the three participants (child 1, 2, 3). 135
Table 12	Results from the SDQ-Deu questionnaires. The SDQ scores for each construct are compared against the general population and can result in high, slightly high, average, or low scores. We show the score of each participant by placing the participant's abbreviation in the corresponding cell. 136
Table 13	The table summarizes the measures of the case-studies and how they were measured in terms of interview items or behavior annotation from observations. 142
Table 14	The table provide a detailed description of the four forced choice help tests devised to measure tendency to help the robothing after the game. Abbreviations in the table are as follows: R stands for robothings, C stands for child. 144
Table 15	The table presents the annotation scheme of the analysis of children's understanding of the robothing behavior. 145
Table 16	The table details the coding scheme of the to analyze the outcomes of the role-play activity with the puppet. We analyze the movements children made while puppeteering taking into account goal-direct behaviors, motion parameters and trajectory. 182
Table 17	The table details the themes used to analyze children's explanations of their robot behavior designs. 183
Table 18	The table summarizes the actions (goal-directed motion), the Laban Efforts (motion parameters), and direction, (direction of motion) children have used to design prosocial, antisocial, passive intentions of a robothing. In bold, the actions, Laban Efforts, and trajectories that were observed with more frequency in the corpus of co-designed behaviors. 184

Table 19	The table summarizes the actions (goal-directed motion), the Laban Efforts (motion parameters), and trajectories, (direction of motion) children have used to design prosocial, antisocial, passive intentions of a robothing. In bold, the actions, Laban Efforts, and trajectories that were observed with more frequency in the corpus of co-designed behaviors. For a breakdown of the frequencies and more information about the co-design study, please consult Chapter 5 219
Table 20	The table details the codebook used to analyze the open-question: Why do you think Push-one did what it did?. On the right, the codes used to annotate the corpus of answers. In the center, the definition used for each code. On the right, examples taken from the corpus of answers. Please note that the answers are not corrected, but copied as they are with typos and grammatical errors. 267
Table 21	The table details the codebook used to analyze the open-question: What do you think Push-one was doing?. On the right, the codes used to annotate the corpus of answers. In the center, the definition used for each code. On the right, examples taken from the corpus of answers. Please note that the answers are not corrected, but copied as they are with typos and grammatical errors. 268
Table 22	The table lists the adjectives participants could select to describe the social qualities of the robothing behaviors (Ascription of Social Qualities Item). We chose the adjectives used in the survey during a pilot test with adults. Pilot-test's participants clustered the adjectives in three macro-categories of social qualities: prosocial, passive, and antisocial social qualities. Adjectives in the related categories were associated with different conditions, as reported in the third column of the table. 270
Table 23	The table details the codebook used to analyze the open-question: What do you think Laura and Jim were doing?. On the right, the codes used to annotate the corpus of answers. In the center, the definition used for each code. On the right, examples taken from the corpus of answers. Please note that the answers are not corrected, but copied as they are with typos and grammatical errors. 270

Table 24	In the table, the results of the manipulation check for the robothing's action. Numbers in the table are counts, presented per between-subject factors and within-subjects factors. Participants replied to one multiple choice item "What do you think best describes what Push-one did in the video?". Participants' options were: Push-one took away a block, Push-one was giving a block, Push-one was taking care of its own puzzle. 271
Table 25	In the table, the results of the manipulation check for the robothing's motion style. Numbers in the table are counts, presented per between-subject factors and within-subjects factors. Participants replied to one multiple choice item "In what way do you think Push-one was moving in the video?". Participants' options were: Push-one took away a block, Push-one was giving a block, Push-one was taking care of its own puzzle. 272
Table 26	The table reports the coding findings of the question "What do you think Push-one was doing", to discern the legibility in terms of actions the robothing behaviors. We report counts and percentage per within and between-subject factors. 283
Table 27	The table reports the coding findings of the question "Why do you think Push-one did what it did?", to discern the legibility (intention) behind the robothing behaviors. We report counts and percentage per within and between-subject factors. 284
Table 28	The table reports the results of the ascription of social qualities. The table shows the distribution of the counts of the adjectives over between and within subjects factors. The table reports the values of the standardized residuals as well (abbreviation, std.res). The values of the standardized residuals are used to interpret the results of the Pearson Chi-Square test. A value higher than 1.96 or lower than -1.96 is considered significant at a $p < 0.05$. Significant values are in bold. 285
Table 29	The table details the codebook used to analyze the behavioral responses of children after the robothing's intervention in the conflict. From the right, the code, then the definition and lastly examples from the audio-video recordings. 307

Table 30	The table details the codebook used to analyze the open-question: ‘Why did Push-one did what it did with the puzzle piece?’ for our manipulation check. On the right, the codes used to annotate the corpus of answers. In the center, the definition used for each code. On the right, examples taken from the corpus of answers. Please note, the answers are not corrected, but copied as they are with typos and grammatical errors. 309
Table 31	Manipulation check counts results of the question: ‘What action was Push-one doing in the game’ 310
Table 32	Results (counts) from the coding of the question: ‘Why did Push-one did what it did with the puzzle piece?’ 310
Table 33	The results of the annotation of prosocial behaviors (prosocial or none) per experimental condition after the game. Data are counts and standardized residuals (i.e., residuals). Standardized residuals in bold indicate significance. 317
Table 34	The number of children that helped the robot at the end of the experiment divided over the conditions. Data are counts. 317
Table 35	The number of stickers, 6 had to be distributed, children allocated to the robot, the other child, or themselves after the experiment. 318

LIST OF TABLES

INTRODUCTION

Play is the work of a child.

Maria Montessori
Il Metodo (1909)^a

^a I suggest to listen to **1812 Overture, Op.49** by Pyotr Ilyich Tchaikovsky while reading this chapter.

"Hey! That is my piece of puzzle!! I need it, N-O-W!!!!!! Don't be nasty, Lucas" - says Anna hastily to her big brother.

"No, its M-I-N-E!!!" - chuckles Lucas pulling the piece of puzzle towards him, *"All the toys are mine anyways, Anna, you know that"* - Lucas declares triumphant with a confident smirk.

"No, no, no, I need it, Lucas, c'mon" - Anna huffs and puffs, feeling defeated.

While Lucas is savoring the victory over her little sister, he hears a sudden squiggly sound *"What is that!!!!!!"*. - he shouts out jittery.

Anna opens her eyes and mouth wide open. She can't believe her eyes. Her wooden toy, the smooth one with wheels, the one she loves to tell adventure stories to, the cute one with a bright red shovel in front, that toy is moving towards her carrying a puzzle piece of Lucas. Nobody is moving the toy, the toy is moving on its own. The toy pushes slowly, but steadily a triangle-shaped puzzle piece in front of her and then drives back to its original spot.

"Wow, the triangle told that toy to bring it to you, Anna!!!! The triangle controls all the toys!!!" - Lucas shouts agitated while pointing at the triangle piece on the floor.

"No, Lucas, it's the thing, it's the toy! Look, it wanted to help me, it is not nice to fight." Anna affirms looking at her brother with a bitter-sweet mix of awe and confusion.

Lucas is flabbergasted, he cannot contain his excitement. He realizes, it would be nice to play all together, with the toy too. *"Ok, let's not fight anymore. Here, I give you the piece back Anna, let's play together now ¹"*.

The reader might recognize a younger version of herself in the above story of conflict. Alternatively, the reader might recognize behaviors that children sometimes have when they play together. Play is a fun activity, but it is also learning. Play involves learning and training vital social skills, like collaborative skills.

What if the toys children play with becoming socially interactive, support children's collaboration through play? What if the objects children play with

¹ This is a fictional story inspired by true events. The story is inspired by the children I have had the fortune to encounter during the 4 and half years of my doctoral research.

could stimulate prosocial behaviors and reciprocity in collaborative play? What if the technology we design for children could nurture the social skills of children through play? What if playful technology for children could nurture children's reflection about how to collaborate in play without prescribing but enabling children's agency?

This dissertation motivates, theorizes, operationalizes, and evaluates the design space of toys endowed with social robotic technology to support children's collaboration in play. The research is a promising step towards the toys and the technology of the future. Toys and technology that enable learning through play giving agency to the child. Toys and technology for a future designed for and with children.

1.1 MOTIVATION, OPPORTUNITIES AND CHALLENGES

1.1.1 *Going Beyond the Social Robotics Status Quo: Designing Robothings for Children*

Technology plays a significant role in the life of children [212]. Analog technologies (e.g., educational toys) [212] and digital technologies (i.e., computing systems and applications) [90] are essential tools for children's development. In recent years, the advances in robotics technology have boosted the development of socially interactive technology for children, like social robots [27]. Social robots are embodied as artificial agents capable of social communication in human-like ways [39, 67]. Media ² and educational specialists ³ present social robots as a promising staple for future classrooms and playrooms. The critical premise is that social robotic technologies will relieve overburdened educational systems and provide opportunities for children to foster competencies in a personalized way [27], including socio-emotional competencies like collaboration. Social robots successfully leverage their ability to communicate socially and (potentially) bond with children to tutor children in various educational settings [25]. Social robots that tutor children, often called tutoring robots, support their formal [287] and socio-emotional learning [324]. Tutoring robots have so far represented the status-quo of social robotics research. Stemming from the theory generated by and considering the limitation of child-robot interaction, this dissertation attempts to go beyond social robotics' status quo for children.

The Social Robots Status Quo

Tutoring robots instruct, explain, and scaffold children to understand complex concepts. Social robots and tutoring robots leverage human-like roles (i.e., tutor, teacher, peer) and formal education strategies. They often focus on one-o-one interactions. Child-robot interaction research has shown that social robots for children and tutoring robots positively impact children's learning. Findings from a battery of HRI studies show that robots significantly impacted learning outcomes [208, 225, 287]. Social robots help children by explaining concepts [395], they support meta-cognitive strategies to deal with problem-solving tasks [287], they improve children's language skills [209] and support conflict resolution [324]. However, like many analog and digital educational devices in the past, social robotic technology brings notable limitations, along with exciting opportunities for innovation [25, 27, 318]. From a technological perspective, social robots are usually too expensive and not sufficiently robust to move out of laboratory settings into children's real world. Social robots are rarely able to deal with the

² Rebecca Mead Learn Different, Silicon Valley disrupts education, The New Yorker (2016).<https://www.newyorker.com/magazine/2016/03/07/altschools-disrupted-education>

³ Omar Mubin and Muneeb Imtiaz Ahmad, Robots likely to be used in classrooms as learning tools, not teachers <http://theconversation.com/robots-likely-to-be-used-in-classrooms-as-learning-tools-not-teachers-66681>

complexity of in-the-wild scenarios and rarely afford group interactions [225]. The technological limitations of social robots harm child-robot interaction [27]. Recurrently, children experience a mismatch between what a social robot can do, technically and socially, and what children expect the robot to do [25]. Human-like appearances, behaviors, and roles deceive the children, who ascribe much more intelligence and capabilities to the robot than the robot has [86]. The mismatch children experience diminishes the engagement with the robot or even distracts from educational activities [194]. This mismatch nurtures a feeling of deception and mistrust that, in the long run, is detrimental not only for the children's education but negatively impacts their understanding of agency and their morality judgments [188]. Interventions focus on formats of formal education [27, 69]. By replicating formats and activities usual in school education, tutoring robots might bring more challenges than solutions. For instance, teachers question a robot's ability to offer a meaningful learning experience and wish for a robot to take a complementary pedagogical role and focus on playful interaction [318]. By focusing on one-on-one tutoring of a child [69], social robots tend to neglect interactions with groups of peers, which is essential for children's development [300]. All in all, the positive impact on children's learning and social behavior is undeniable [189, 208, 287], but so are the concerns related to human-like tutoring roles, interventions, and behaviors. How to make good use of the social interaction a robot affords while minimizing children's feeling of deception? How can we enable design space explorations of robots with fewer anthropomorphic features, roles, and behaviors? How can we extend the context of the use of social robots towards applications that do not replicate human tutor interventions? How can we enable peer interaction in child-robot interaction?

Researchers in Human-Robot Interaction and Child-Robot Interaction are increasingly addressing these questions by exploring new forms, roles, and pedagogical paradigms for social robots for children [7, 235]. Scholarly work is progressively exploring abstract-looking robots that resemble educational objects or toys: Social robots with less human-like behavior and human-like roles, or even simple robotic objects that show intent [299]. These robots are shifting social robotics applications for children from tutoring paradigms to playful paradigms where children learn through play [235]. Playful paradigms could be particularly fruitful to support socio-emotional competencies like collaboration. Why? Because play is the primary locus of social and emotional learning. Learning collaboration skills through play could represent a developmentally appropriate way to promote children's collaboration. This dissertation positions itself in the body of child-robot interaction research that is challenging the status quo of tutoring paradigms with playful paradigms.

The research explores how robotic technology that looks similar to the objects children play with and does not have a set of human-like modalities could promote collaboration among children. Cost-effective, simpler robots

rely on minor anthropomorphic cues to positively influence children's behaviors. While the status quo in child-robot interaction focuses on tutoring interventions to verbally motivate children to behave in specific ways, this dissertation considers playful interventions to nonverbally stimulate children to behave prosocially and collaborate when playing together. Imagine a robotic cleaner that shares toys with children to stimulate reciprocity during playful tidy-up. Imagine a robotic toy that intervenes in children's conflicts over objects' possessions by giving new objects or taking away the objects children are fighting about. Furthermore, this dissertation probes the design space of non-anthropomorphic nonverbal social communication for robots. Imagine a robotic blob providing helpful information to children only with its rotation movements or a robotic toy that communicates prosocially only with its motion. The dissertation will refer to these robots as *Robothings*. The term *robothing* derives from the term *robot* and the term *thing*. The prefix 'robo' is an abbreviation of the word *robot*. It indicates an autonomous artificial agent that is embodied and behaves. The suffix *thing* is related to the word 'thing', but it connects with the concept of things developed by the philosopher Bruno Latour [215]. For Latour, everyday objects are not inanimate, nor are simple tools. Objects shape how we perform actions (e.g., a crutch changes the way we walk); they extend our capabilities (e.g., the microscope extends our vision capabilities), shaping how we make sense of ourselves and the world, supporting and influencing how people act and make sense of the world. Thus, conceptually *robothings* refer to things as a robotic mediator of the children-world relationship. Concretely, *robothings* are hybrids between objects and social robots. *Robothings* are low/non-anthropomorphic robots that communicate their prosocial intentions to influence people's behaviors, leveraging their nonverbal communication affordances. We conceptualize the role of a *robothing* as an interactive "thing", with its agency, rather than a human-like partner (e.g., teacher, friend) that aims at a human-like agency. For this research, we explore *robothings* only in child-robot interaction.

Robothings

1.1.2 *Intervening in Collaboration between Children: Exploring Playful Interventions*

Collaborative skills are the most sought-after socio-emotional competencies for 21st-century children⁴. Collaborative skills include a wide array of prosocial competencies and behavioral strategies to carry out joint activities [300]. Despite their importance, collaborative skills are often overlooked in educational systems worldwide. A recent study from the Organisation for Economic Co-operation and Development (OECD) [360] found that lack of collaborative competencies regularly correlates with unfavorable outcomes

⁴ <https://www.unicef.org/child-rights-convention/open-letter-to-worlds-children#21-century-skills>

How Children Learn to Collaborate

later in adult life increased chance of unemployment, divorce, poor health, criminal behavior, and imprisonment. The Sustainable Development Goals ⁵ set by the United Nations consider collaboration an essential competence for children, which society needs to foster more. Children learn how to engage in collaboration early in their development [17], but children do not automatically co-operate, help each other, share resources, or avoid conflicts [319]. Children are often unable to collaborate well due to difficulties in regulating prosocial behaviors to deal with interpersonal dynamics with peers: knowing when to help, when to share, how to solve a conflict is not trivial for children [248]. Typically, middle-childhood (7 to 11 years old) is the pivotal moment for children to train their collaboration skills [283]. Schools intervene to nurture children’s collaborative skills through tutoring, and evidence-based educational programs [130]. These programs revolve around hypothetical collaborative scenarios and teaching children strategies to apply in those scenarios [111]. Unfortunately, evidence-based strategies are hardly applicable in real-life scenarios, which are more complex and multifaceted than hypothetical scenarios. Real-life practice through play with peers is the best way for children to master collaboration [97, 281, 300]. However, play-based opportunities for training collaborative skills and nurture prosocial behaviors are less and less available to children [109], especially in elementary school. Therefore, the impact of school interventions often remains at a surface level. Many of the proposed technological interventions to nurture collaboration suffer from similar limitations. Social robots that promote collaboration have applied tutoring approaches with mixed success [354, 324].

The Role of Prosocial Dynamics

A promising alternative is to leverage the reciprocal and prosocial dynamics occurring in natural interactions [97]. When we interact with somebody that helps us, we are compelled to help in return [264]. When we work in a team, we tend to collaborate more with each other when teammates share resources and information with us [249]. Children experience a similar effect when playing together [284]. Research shows that mere exposure to the action of helping or sharing of one child in play leads to reciprocity and a greater tendency to be prosocial in the short and long term [101]. Actions such as helping, sharing, and informing establish the prosocial norm and prompt reciprocal dynamics in a group [96]. Prosocial and reciprocal dynamics promote collaboration, even when collaboration is challenging [248]. A shift towards playful paradigms to support children’s collaboration favors the natural way children learn to collaborate.

This dissertation examines how to adopt playful paradigms to promote children’s collaboration with robotic technology. Would a robothing that exhibits prosocial behavior impact reciprocal dynamics that promote children’s collaboration? An open design question is how to design the interaction with a robothing in play to impact reciprocal dynamics. We know from the litera-

⁵ <https://www.un.org/sustainabledevelopment/sustainable-development-goals/>

ture that children consider the behavior of a robot social [67] and that effects for human-human interaction replicate in some instances in human-robot interaction [291]. However, we do not know how a robothing can achieve such effects only through playing with children, rather than instructing them or scaffolding their actions through verbal interventions. Literature shows that children regulate collaborative dynamics in play mainly through actions and nonverbal behaviors [248], hence playing could be sufficient. Nonetheless, while we know how to design nonverbal behaviors for human-like robots, there are fewer guidelines for low/non-anthropomorphic robots, like robothings. Hence, it is hard to design non-verbal playing behaviors that achieve such a complex communicative goal. This dissertation addresses the gap mentioned above, actively exploring how to operationalize playful interaction with a robothing and how to design nonverbal behavior for a robothing to intervene in children’s collaboration.

1.1.3 *Human-like Communication vs. Communicating in ‘Human terms’: The Challenges of Designing Robothings’ Communication*

A robot needs to communicate its states, goals, and intentions to interact with humans [67]. A robot communicates by leveraging the interplay of surface appearance and physical motion, sound, and illumination modalities [258]. Movements [151], sounds (both verbal [195], and nonverbal [409]), and lights in isolation or together constitute the way a robot behaves to communicate. How are robots’ behaviors designed to communicate with humans socially? So far, social robots communicate in ‘human-like ways’. A robot leverages communication modalities that humans have [67] (e.g., speech, natural language, facial expressions, human-like gaze, hand gestures, human-like head movements, human locomotion) to communicate socially with a human. A robot should behave as humans do (e.g., flowing conversations, back-channeling speech, coherent expressions of emotions, appropriate approaches, articulate gestures) using cues, modalities resembling humans’ ones. The primary assumption in social robotics is that robots should adhere as much as possible to the modalities and ways humans communicate [39, 20]. If a robot communicates in human-like ways, humans apply existing mental models and social norms to understand the robot’s communication, interacting with the robot as they would do with another human [18].

*Communicating in
‘Human Terms’*

An opposite strand of HRI research focuses on designing robot communication that is not at all or less human-like [151, 228, 356, 355]. To this end, researchers have resorted to a plethora of techniques. Animation principles [295] and animation techniques [151] have been used to imbue abstract non-anthropomorphic robots with social behavior as animators do with virtually anything they draw. Theatre [203] and improvisation techniques [332, 228] have been adopted to instill expressivity into low/non-anthropomorphic robots. Designers have delved into the design of robot

behaviors optimized for low-anthropomorphic specific morphologies, achieving social communication with modalities that are not human-like [191]. A common denominator of these approaches is designing to communicate in ‘*human terms*’ rather than in human-like ways. Humans have the propensity to anthropomorphize abstract motion and perceive it as socially communicative [142]. A robot communicating in ‘human terms’ leverages the tendency of humans to attribute states, goals, intentions, emotions, and social traits to virtually anything that moves in a contingent way in the space [240]. Thanks to this human propensity, low/non-anthropomorphic robots’ motion and nonverbal behaviors alone cue what actions and interactions are possible. As a result, communication in ‘human terms’ relieves robots from the need for a human-like form or human-like modalities.

Design Challenges

The HRI scholarly work has so far unveiled several dynamics of the communication in ‘*human terms*’, but there are still crucial challenges to address. First, it is hard to anticipate how people interpret a robot’s motion or nonverbal behavior [207]. A comprehensive theory of the interpretation of the motion of an agent under various interactive circumstances is missing. Furthermore, the design implications from the HRI literature might not generalize for every low/non-anthropomorphic robot. The variability of interpretation is already high when a robot communicates in human-like ways [183]. Therefore it is arduous to design a robot behavior that effectively communicates in ‘human terms.’ Especially for children, who have different ways of understanding animacy and agency of ‘things’ that behave and have more difficulties expressing themselves [3, 268]. The design methods applied to design a robot’s communication are effortful, and there is no consensus regarding best practices and design processes. While research has shown how potent the communication in ‘*human terms*’ can be, coherent and comprehensive design guidelines are missing. The child-robot interaction literature is particularly scarce on the matter.

This dissertation explores what it means for a robothing to communicate in ‘human terms’ to children. By leveraging nonverbal communication in ‘human terms’, a robothing could mitigate the adverse effects humanoid robots might have by relying only on low/non-anthropomorphic cues and behaviors. However, there are many gaps in the literature. Little is known about the essential elements required to communicate in ‘human terms’ or communicate a robot’s intention effectively solely with non-anthropomorphic and nonverbal communication. An urgent question concerns how to design behaviors and interactions under the premises of communication in ‘human terms’. Overall, the explorations of a robothing communication demand a deeper understanding of communication mechanisms in ‘human terms’, especially when designing for children.

1.1.4 *Design for and Designing with Children: Involving Children in the Design Process*

Current methods exacerbate the challenges of designing low/non-anthropomorphic social communication for child-robot interaction. Children are still developing their abilities to understand other people's minds (i.e., Theory of Mind) [17]. As a result, children tend to blur the boundaries between animate and inanimate more than adults do, easily endowing robots with agency [3, 281]. Children easily engage in the pretense that a robot is alive and an entity [189, 268]. While the propensity of children to play along with the illusion of life is beneficial to establish child-robot interaction [25, 189], it can also have deceptive effects [86], raising ethical issues and detrimental effects on robots' interventions [188]. Researchers only understand the impact of the designed child-robot interaction partially and late in the design process, only during the evaluation. It is hard to understand how children interpret robot behaviors and perceive a robot [25]. Results for user testing are often surprising [194]. Children endow robots with animacy and agency in ways designers do not expect [86]. Current evaluation methods repeatedly fall short to account for children's experience because children find it hard to respond to surveys [225, 243]. Children have tacit knowledge about their experience with robots, but questionnaires, observations, and interviews usually are unable to tap into this knowledge [243, 90].

Children and the Illusion of Life

The field of child-robot interaction would benefit from methods that tap into children's tacit knowledge about robots and from methods that include children's views in child-robot interaction design. Child-robot interaction (and human-robot interaction) is an interdisciplinary field where engineers, roboticists, computer scientists, and designers collaborate. On top of the different approaches, the research practices of engineering and social sciences are predominant. While often user-centered, these practices consider involving users in the design process solely during the designs' formal evaluation. Recently, child-robot interaction researchers are venturing into research design methodologies, such as co-design, that involve children early in the design process [7]. Co-design with children entails involving children in the design process to co-generate design solutions [90]. The co-generation process consists of generative activities tailored to children's abilities to tap into the tacit knowledge of children [88]. While there are first attempts to develop co-design methods to design robot behavior that communicates in human terms with children [7], established methods or validated rationales are not available. This dissertation ventures into the uncharted field of co-design for child-robot interaction.

The Opportunities of Co-design

1.2 AIM AND RESEARCH QUESTIONS

This dissertation tackles the opportunities and challenges of designing robothings to promote collaboration among children in play. The section elaborates on the principal aim of the dissertation and formulates the questions that guide the research. We have defined Robothings as low/non-anthropomorphic robots that communicate their prosocial intentions to influence people’s behaviors, leveraging their nonverbal communication affordances. Two facets are central in designing robothings to promote collaboration among children in play. The first facet is the operationalization of the robothing’s intervention and the effects on children’s collaboration of such an intervention. The second facet is the design of effective robothing’s communication with non-anthropomorphic affordances and nonverbal communication. As a result, the dissertation has two overarching aims:

- AIM 1: To investigate how robots that have less human-like form and behaviors can promote children’s (7-11 years old) collaboration through play; and
- AIM 2: To probe the design space of non-anthropomorphic nonverbal social communication in child-robot interaction.

The two aims translate into research questions. A prerequisite to investigate how to promote children’s collaboration through play is to picture how children collaborate in play. Literature provides information regarding how collaboration unfolds in play, particularly about the centrality of prosocial behaviors and reciprocal behaviors to regulate collaboration. However, previous work does not explain how exactly children regulate prosocial behaviors to collaborate in play. Little is known about the exact behaviors children exhibits during collaboration in play. Knowing how a child acts, reacts, and regulates behaviorally prosocial behavior during collaboration in play is essential to envision the interaction scenarios for a robothing and detailing opportunities for a robothing’s intervention. It is necessary to have a granular knowledge of children’s behavior in collaboration to design the intervention of a robothing. Therefore, we ask the following question:

- RQ1. *How do children regulate prosocial behaviors to collaborate in play?*

The dissertation embraces playful paradigms to support children’s collaboration leveraging prosocial and reciprocal dynamics. Prosocial and reciprocal dynamics are complex social dynamics, challenging to regulate for adults and children alike. It is unclear how a robothing could insert itself into children’s prosocial dynamics and sort the desired effect to stimulate reciprocation and collaboration. Little is known about what actions and expressions a robothing should exhibit. Also, it is not clear when and how a robothing should intervene. Thus, we ask:

- RQ2. *How should the interaction with a robothing be designed to impact prosocial dynamics in play?*

Crucially, a robothing must communicate its intention in order to intervene in the collaboration of children. As covered in the above sections, a robothing should communicate in ‘human terms’ to children. The explorations of a robothing communication demand a deeper understanding of the mechanisms underpinning the communication in ‘human terms’. Moreover, a designer needs to translate a complex social communication mechanism into actionable guidelines for design, particularly challenging with children. The children’s population brings unique challenges to design, therefore complicating the designer’s task. Consequently, we pose the following question:

- RQ3. *How should the nonverbal behavior of low/non-anthropomorphic robots be designed to communicate a robot’s intention to children?*

A second fundamental aspect of the design of the nonverbal behaviors of robothings is discerning how children interpret it and perceive it in context. Literature shows that any misunderstanding in human-robot interaction is detrimental for the desired interaction outcomes [18]. A prerequisite to an effective interaction is a correct interpretation of the intended meaning of a behavior [240]. Depending on the interpretation, children will respond accordingly. Should the interpretation be incorrect, the robothing intervention might fail. Not only is it important to assess children’s interpretation of robot behaviors, but it is also imperative to investigate how children perceive a robothing to be. The behaviors of robots appear to influence children to attribute a diverse range of social qualities. In turn, the attribution of social qualities interplays with the effectiveness of a robot’s communication. Thus, we ask:

- RQ4. *How do children interpret and perceive the nonverbal behavior of low/non-anthropomorphic robots in play?*

The ways children interpret and perceive the nonverbal behavior of robots might surprise designers and researchers. As discussed in the above section, there is a knowledge gap between designers and children, aggravated by methodological challenges. It is challenging to access the tacit knowledge children have about their experience and perception of robots. Exploring methods to involve children in designing the robothing behavior could mitigate the knowledge gap and enable children to express themselves about robots. Co-design with children is not usual in human-robot interaction. There are not methods, techniques, and tools available yet. At the same time, the methodological resources available from other fields might fall short in child-robot interaction. The interaction with robots is more complex than the interaction with computers. Children’s innate drive towards social interaction with robots calls for methods that are specific for child-robot interaction. Consequently, we ask:

- RQ5. *What method is suitable to co-design the nonverbal behavior of a robot with children?*

Lastly, once communication between a child and a robot is achieved, a robot can affect children's behaviors. Crucially, we need to discern how the envisioned intervention of a robothing plays out in child-robot interaction. We cannot fully anticipate whether the positive effects of interacting with a prosocial person might replicate with a robothing; neither can we completely foresee collaboration effects. To understand whether a robothing can promote collaboration through play, we ought to investigate:

- RQ6. *What are the effects of a robothing behavior on the prosocial behavior and collaboration of children in play?*

Together these six questions address the two aims of the dissertation thoroughly, covering the 'ABCs' of robothings to promote children's collaboration in play. The research questions provide the basis for more specific questions addressed in the chapters of the dissertation.

1.3 RESEARCH APPROACH AND METHODS

HRI has to do with the design of technology and the relationship between technology. The multifaceted nature of HRI calls for a combination of approaches and methods. In the dissertation, we focus on designing *for* children and *with* children. As a result, we tap into a combination of human-centered and co-design approaches.

In the first part of the dissertation (Chapter 3, Chapter 4, Chapter 5), we take a *human-centered approach* shifting from designing for the children to designing with the children. We take children's perspectives, and we try to understand what to design for them within our scope. Children are involved mainly as testers in user-studies to evaluate our design and as participants of ethnographic research. In chapter 5, we involve children in the design process too. We explore how to design *with* children, embracing a co-design approach. Co-design levels the usual asymmetry between researchers and children, involving children in creating technology with various roles. In the case of this dissertation, children were involved as active informants regarding how to design robotthings. We involve children as informants [88] and develop an *ad-hoc* co-design method (Figure 1 summarizes the levels of involvement of children, while Figure 2 illustrate the levels of involvement and related approaches and methods). Process-wise, we start with understanding children's behaviors, context, and needs and then design according to this knowledge. The process ends with evaluations of the designs and their effects on children.

In the second part of the dissertation (Chapter 6, Chapter 7, Chapter 8), we combine our human-centered approach with a specific approach to robot behavior and robot design, a *movement-centered approach*. The movement-centered approach is compatible with a human-centered approach: The ultimate goal of a movement-centered approach is to surface the people's tacit knowledge about nonverbal behaviors and use this knowledge to design robots carefully. The movement-centered approach, also referred to as designing with movement in mind (as defined by Hoffman and Ju [151]) is a process that factors in mechanics, expressiveness, aesthetics, and people's experience through iterative design explorations. At this stage, we involve the children only to evaluate the designs, but we use the knowledge generated during our co-design sessions (Chapter 5). Process-wise, we add a broader ideation and prototyping phase that focuses specifically on translating knowledge about how a robotthing should move into a robotic artifact. We use a battery of methods to execute our approach, which we introduce in the next section.

1.3.1 Methods

The research draws on an array of research methods originating in the social sciences (i.e., analog observation, behavioral observation, behavioral

experiments), in human-robot interaction (video-based human-robot interaction studies and human-robot interaction studies) and design-research (i.e., ideation, prototyping, co-design, generative improvisations, workshops). These research methods result in empirical, qualitative, and generative knowledge to answer the research questions.

Analog observation is a method that offers an analytical window in how children think about robotothings, feel about the experience with robotothings, and behave when interacting with robotothings. We use these methods to understand how children behave (Chapter 3).

Video-based human-robot interaction (VHRI) studies and human-robot interaction studies are methods to discern people's perception of and experience with a robot. VHRI is used in this dissertation as both an empirical and prototyping device to gain fine-grained and internally valid knowledge about robot behaviors in context. Through VHRI, it is possible to present a relatively high number of video-stimuli in a highly controlled manner and survey children about their video-stimuli perceptions. VHRI is particularly useful in the robot's behavior design process to validate robot behaviors that can then be evaluated in in-person studies. Developing a fully functional robot and an experimental protocol to test design options is too costly and laborious. Human-robot interaction studies investigate user experience with a robot either in the laboratory or in the wild. Robots can be either autonomous or remotely controlled. This dissertation presents several user studies in which the robotothings are remotely controlled. Therefore, the studies use a Wizard-of-Oz (WoZ) approach. WoZ is a potent device to carry out user evaluation of a design prototype. Developing a robot with full autonomy to evaluate a design prototype is not convenient. In our process, we often validate how children perceive and read a robotothing behavior in VHRI and then evaluate the effect of a robotothing behavior *in-situ*.

VHRI and WoZ

In the dissertation, ideation, prototyping, and co-design methods are used to tackle the research design aspects. The research shares some methodological perspectives with research-through design because the scope of design is to produce knowledge about robotothings, not to inform the development of a commercial product [417]. However, it has stronger ties with human-centered design methods in design-research. Robotothing behavior prototypes are distilled from principles gathered from a theoretical, conceptual framework and co-design activities with children. The form and appearance of robotothings are designed via design improvisations, low fidelity prototyping, role-playing, and puppeteering. Workshops are used to evaluate the co-design methods and carry out low-fidelity prototyping (i.e., designer workshops and play-testing).

*Design-Research
Methods*

1.4 STRUCTURE AND OUTLINE OF THE DISSERTATION

The dissertation presented in this book is divided in two parts: Part i and Part ii. Part i consists of four foundation chapters (Chapter 2, Chapter

Figure 1: In the figure, a visualization inspired by Druin's taxonomy of children's involvement in the development of technology [88] and van Doorn's one [82]. The figure is showing the roles children take in the design process. We highlight the role of informant, as children take this role in Chapter 5 to co-design robotthings' behaviors.

Figure 2: In the figure, a reproduction of a figure by Bont et al. [35]. The figure shows the level of involvement of people in the design process and maps the methods we use in the dissertation into the various levels.

3, Chapter 4, and Chapter 5). The chapters provide the 'ABCs' to design robotthings that promote children's collaboration through play. Part i details the conceptual framework and the design principles resulting from the framework. Part i reports empirical design explorations that provide essential insights about how to design robotthings' behaviors and children's perception of robotthings' behaviors (See Figure 3 for an overview of the robot platforms studied in Part i). Lastly, Part i proposes a method to involve children's views in the design process of the behaviors of robotthings.

Figure 3: In the figure, the robot platforms which we used to explore the design space of robothings. We worked with four different robots. In the figure, we detail whether the robot is (i) low or non-anthropomorphic, (ii) whether the robot is autonomous or remote-controlled, (iii) the primary interaction modality, and (iv) whether the robot is commercial or developed in research settings.

Part [ii](#) builds upon the knowledge gained to design, develop, and evaluate a proof-of-concept robothing. Part [ii](#) consists of three chapters (Chapter [6](#), Chapter [7](#), Chapter [8](#)). The chapters present the design process and empirical evaluations of Push-one (See Figure [3](#)) and its behaviors, a proof-of-concept robothing artifact. Push-one is designed according to the conceptual framework, the design principles, and guidelines. Its behaviors derive from the co-design activities with children.

Finally, the last chapter of the dissertation (Chapter [9](#)) discusses findings, implications, and limitations and concludes the dissertation. The dissertation has an Appendix (Appendix [A](#)) in which extra materials are provided. Appendix [A](#) is organized into sections; the title of the section describes the content of the section and links to the corresponding chapters.

Figure [4](#) provides a visual overview of the structure of the thesis and the research questions tackled in each chapter. Table [1](#) provides an overview of the dissertation’s studies. Below, a detailed outline of the Chapters.

1.4.1 Part [i](#). The ABCs of Designing Robothings to Promote Children’s Collaboration Through Play.

- Chapter [2](#) introduces the theory, background knowledge, and related work that ground the dissertation and the conceptual framework resulting from the literature analysis. First, we present a critical analysis of cHRI literature on social robots. Our goal is to discern what the current status quo in cHRI is. We think that social robotics technology is ideal for children’s collaborative play, but we want to identify responsible

design opportunities mindful of children’s development and minimize ethical concerns. Second, we review the developmental psychology and child sociology literature about collaboration, prosocial behavior, and the social dynamics relevant in collaboration. The goal is to pin-point and unpack the dynamics we should intervene in when designing to promote collaboration. As much of the learning of collaborative skills happens in play, we review the literature about play in general and collaborative play to look for design opportunities. Third, we survey how designers of children’s technology have designed interventions in collaborative play. Fourth, we hone-in on how to design social robot communication to achieve cHRI effectively. The goal of our analysis of related work and theory is to discern how we could design robots to maximize a responsible illusion of life: communicating vividly to children without deceiving them and raising unattainable expectations. The chapter’s ultimate result is a conceptual framework derived from the literature analysis. The conceptual framework is the synthesis of the literature analysis and guides us in setting up and carrying out the research. Through the lens of the conceptual framework, we introduce the motivation and definition of robothings. The framework also offers seven design principles that guide our robothing behavior design. All subsequent chapters draw from the conceptual framework introduced here. Ultimately, Chapter 2 contributes to answering RQ1 and RQ2.

- Chapter 3 presents a behavioral observation study. In this study, we observed children engaged in collaborative play. We sought to understand what prosocial and conflict dynamics children exhibit, the role of prosocial and conflict behaviors in regulating collaborating play, what group dynamics emerge, and how the type of task impacts children’s behaviors and dynamics. This knowledge helped us identify design opportunities. We show that children find it hard to regulate the social dynamics of collaborative play. Children resort to conflict more than they show prosocial behavior. Children tend to play in sub-groups instead of playing with all the group members. The group dynamics show that children tend to dominate or exclude other children from collaborative play dynamics. We also observed that the type of collaborative play task plays a role in enabling more or less collaboration. In particular, collaborative games with rules support the emergence of collaborative dynamics, while in open-ended tasks, children play less together. The findings of the observation study inform our scenario design. Chapter 3 contributes to answer to RQ1.
- Chapter 4 focuses on how robothing behaviors can be designed to communicate to children without human-like appearance, modalities, and behaviors. According to the framework presented in Chapter 2, robothings should be designed to communicate in ‘human terms’, that is, to leverage the human tendency to perceive self-propelled objects

that behave in contingent ways as agents and infer their intention solely from movements and actions. To this end, we explore nonverbal modalities, like a robothing’s minimal motion, locomotion, actions, and nonverbal sounds to communicate sharing, helping, and taking intentions in collaborative play. Chapter 4 details findings from empirical evaluations of the behaviors (Study 2, Study 3) and a longitudinal case-study (Study 4), which show that it is possible to legibly communicate a robothing’s intention only with minimal motion (gaze-movements), locomotion, and actions like nudging and giving or taking away resources. Motion and action appear to override nonverbal sounds too. Moreover, our case-study provides the first indications that robothings affect collaborative play dynamics: robothings influence children’s social motives to collaborate and reciprocate with one another in collaborative play. Chapter 4 contributes to answer to RQ3, RQ4 and RQ6.

- In the previous chapters, we have learned that children’s perspective on robot behaviors deviates from what designers usually expect. While the challenges of designing social robots for children are known in the literature, it is not easy to address them with current cHRI methods. Specifically, we identify a methodological gap: there are not design methods in cHRI to account for the way children make sense of a robot’s behavior and ultimately agency (i.e., its capacity to act independently and perceived intentions to do so). In particular, we argue that classic human-centered design methods, such as observations or interviews, might fall short in accounting for how children experience a robot’s behavior and agency. Much of the literature in child-computer interaction shows that co-design, focusing on co-generation, could be better suited to tap into children’s tacit knowledge of a robot’s agency. Hence, in Chapter 5 we explore methods to involve children’s perspective of robot behavior and agency in the design process. In the chapter, we introduce a co-design method to include children in the design of robothing’s behaviors: Perspective Taking in Embodied Role Play (PeerPlay). The PeerPlay method consists of two activities, Exploratory PeerPlay and Behavior Authoring PeerPlay; the former is developed for the initial design process when a robot platform is not defined yet. The latter is geared to mature stages of the design process, during middle and high-fidelity prototyping. The method centers on role-playing and perspective-taking, central phenomena in children’s understanding of agency. We co-design and co-generate robothings behavior with Peer-Play while enabling children to reflect on a robothing’s agency. The chapter reports two co-design workshops with children (Workshop 1, Workshop 2) to explore the PeerPlay method. Chapter 5 contributes to answer to RQ5.

Figure 4: The figure is visualizing the structure of the dissertation. The visualization in using the metaphor of primary shapes to break down the flow of the dissertation. On top, the initial situation. Chapter 1, the Introduction, poses fundamental questions. The dissertation goes through two cycles to answer the research questions. Part I explores the foundations of the design of Robothings, the 'ABCs'. Chapters in Part I constitute a unity of sort, represented by the circle shape. Part I informs, guides, grounds a subsequent research cycle. Part II is a process from design to evaluation of a Robothing to promote children's collaboration. Both parts contribute to answering the research questions, discussed in Chapter 9

Study	Research Design		
	Robot	Methods	Participants
Study 1 Chapter 3	-	Analogue observation	n=21 n groups= 7
Study 2 Chapter 4	Festo Robotino	Video Based HRI questionnaire	n children=72
Study 3 Chapter 4	Festo Robotino (WoZ)	cHRI behavioral study behavioral observation	n=18 n groups=9
Study 4 Chapter 4	Squirrel Robot (WoZ)	Mixed-method case-study longitudinal	n=3
Workshop 1 Workshop 2 Chapter 5	Low-fi puppet Brobotino	Field-trials analysis co-design outcomes	n=20 n=82
Study 5 Chapter 7	Push-one	Video Based HRI, mixed-methods	n children=90
Study 6 Chapter 8	Push-one (WoZ)	cHRI behavioral study, mixed-methods	n children=60 n groups=30

Table 1: The table is summarizing the studies reported in the dissertation. The first column describes the study and indicates where is the study reported. The following three columns briefly summarize each study's research design, indicating the robot, methods, and participants of the study.

1.4.2 *Part ii. Design and Evaluation of a Robothing to Promote Children's Collaboration through Play*

- Chapter 6 presents the design process of Push-one, a proof-of-concept robothing. Taking a movement-centered approach, we translate the movements children have designed during the Exploratory PeerPlay workshop into a remotely controlled robothing prototype. Push-one's embodiment follows its function (what it does) and its communication (what it wants to achieve by interacting). The result is an abstract, non-anthropomorphic, non-verbal, animated wooden-toy that assembles geometrical wooden puzzles. Push-one is remotely controlled and mobile; it has holonomic locomotion. It can move in any direction; it has non-reprehensible manipulation. It can push-objects in a specific direction to a shovel-like front. Push-one operates specifically during children's conflicts around the possession of objects. If children start conflicting about the possession of an object, Push-one gives an extra one to them. Or, it takes away the object children are fighting over to forcibly stopping the fight. These actions represent a way to intervene in the conflict, and they underline strategies children naturally use to resolve disputes. By doing so, Push-one operates to stimulate children to reflect on the conflict and find a way to be prosocial. As a result, Push-one does not tell kids how to behave in conflict, what actions to take. Push-one is designed to enable children's independent reflection-

in-action about their prosocial or antisocial behavior in a game rather than dictating how it is right to act. Chapter 6 contributes to answer to RQ2, RQ3.

- Chapter 7 reports a video-based HRI study (Study 5). The study sought to understand how a robothing's locomotion communicates to children its intention to intervene in a conflict. Study 5 evaluates robothing behaviors, as distilled from the outcomes of co-designing with children (Chapter 5 and Chapter 6). In previous chapters, we have seen that a robothing communicates its intention to children through various actions (Chapter 4). Simultaneously, the co-design workshops unveiled how children stylized a robothing's locomotion to convey extra information about its intention and social attributes. In this chapter, we explore the interplay of actions to intervene in a conflict (i.e., giving, taking, not intervening, expressed through locomotion only) and three motion styles (i.e., linear, sine-wave, and jerky, which are locomotion styles) implemented in the Push-one robothing (Chapter 6). We sought to assess (i) how children interpret and explain the reason for robothing's actions, (ii) how the behaviors influence children's perception of the robothing's helpfulness in the context of conflicts, and (iii) whether children would ascribe different social qualities to the robothing behaviors depending on the type of action and motion style. The chapter discusses findings and design implications. Chapter 7 contributes to answer to RQ3 and RQ4.
- Chapter 8 reports a Wizard-of-Oz cHRI study (Study 6) to evaluate the effect of a robothing on children's prosocial behavior and collaboration in play. In the previous study, Study 5 (Chapter 7, we have evaluated how different Push-one behaviors to intervene in conflict communicate to children and the interplay between a motion-style and an action. From the results of Study 5, we select two actions (i.e., giving and taking), underlining each a different strategy to intervene in a conflict and one motion-style (i.e., sine-wave). In this study (Study 6), we sought to investigate how a robothing intervening in conflict either with a prosocial strategy or with a coercive strategy impact children's prosocial behaviors and collaboration after the interventions and the children's perception of helpfulness of and collaboration with the robothing and the other children. This chapter sheds light on Push-one's effect in real-life in-the wild-interaction with children. We report results and discuss the theoretical and design implications of the conclusive study of the dissertation. We find that children perceive a robothing and the other child in the game as more helpful and collaborative when the robothing intervenes in a conflict with a prosocial strategy. Children share and help each other more after the robothing has exhibited prosocial behavior. Chapter 8 contributes to answer to RQ4 and RQ6.

In conclusion, Chapter 9 provides a discussion of the main findings in light of the research questions guiding the research. The chapter discusses theory, design, and methodological implications along with the limitation of the research. Chapter 9 concludes with direction for future work.

Part I

THE ABCs OF DESIGNING ROBOTHINGS TO PROMOTE CHILDREN'S COLLABORATION THROUGH PLAY

THEORY, RELATED WORK AND CONCEPTUAL FRAMEWORK

The human way of communicating —by intentionally informing others of things for cooperative motives— comes so naturally to us that we can hardly conceive of any other.

M. Tomasello (2008) ^a

^a I suggest to listen to the songs **Linked and Cirrus** by Bonobo while reading this chapter

Chapter 2 introduces the theory, background knowledge, and related work that ground the dissertation and the conceptual framework resulting from the literature analysis. The chapter's ultimate result is a conceptual framework derived from the literature analysis. The conceptual framework is the synthesis of the literature analysis and guides us in setting up and carrying out the research. Through the lens of the conceptual framework, we introduce the motivation and definition of robothings. The framework also offers seven design principles that guide our robothing behavior design. All subsequent chapters draw from the conceptual framework introduced here.

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2.1 CHAPTER INTRODUCTION

Designing social robotic technology to promote children’s collaboration in play is inherently a multidisciplinary endeavor. Thus, it is fundamental to make sense of the theories and related work from multiple perspectives. It is often necessary to elaborate a conceptual framework to organize such complex information into working paradigms and principles.

This chapter makes sense of the diverse literature that informs the dissertation and introduces the conceptual framework deriving from the literature analysis that guides our research in the subsequent chapters. We position our work within the field of child-robot interaction (cHRI), and we critically assess the literature on social robots for children. Then, we introduce the collaborative play literature examining the literature on collaboration and play in childhood. The literature helps us break down the collaborative play phenomenon and pinpoint the dynamics a robot could intervene upon in collaborative play. Based on this literature, we peruse educational and technological interventions developed to support children’s collaborative interactions and prosocial behaviors in collaborative play and beyond. We critically discuss the pedagogical impact of educational and technological interventions, identify each advantage and shortcomings, and identify the consistent interventions with our scope. We ground the choice to focus on robotings in playful collaborative games (taken in Chapter 4 and 6 as intervention), to support children’s collaborative play dynamics. Then, we hone-in on how to design social robot communication to achieve cHRI effectively. The goal of our analysis of the literature is to discern how we could design robots to maximize a responsible illusion of life: communicating vividly to children without deceiving them and raising unattainable expectations.

Finally, the dynamics, phenomena, and theories are elaborated in a conceptual framework to design robotings. The conceptual framework distills all the learnings of the literature analysis and provides the theoretical and practical foundations of our research. We introduce the seven design principles that follow from this framework and guide our design. The chapter contributes with theoretical grounding for three research questions, namely RQ1. *How do children regulate prosocial behaviors to collaborate in play?*; RQ2. *How should the interaction with a roboting be designed to impact prosocial dynamics in play?*; and RQ3. *How should the nonverbal behavior of low/non-anthropomorphic robots be designed to communicate a robot’s intention to children?*

2.2 SOCIAL ROBOTS FOR CHILDREN

Technology plays a significant role in the lives of children [212]. Analog technologies (e.g., educational toys) [212] and digital technologies (i.e., computing systems and applications) [90] are essential tools for children’s development. Children explore the world by playing with the objects that surround them. In our times, toys and digital technology are the “*things*” they discover the world and learn with.

In recent years, the advances in robotics technology have boosted personal socially interactive technology for children, such as social robots [27]. From an educational perspective, the critical promise is that social robotic technologies will relieve overburdened educational systems [27]. Thanks to social robots, educational experiences will be more and more personalized to each pupil [22]. From a therapeutic point of view, the key promise is similar: social robotic technology will provide tailored therapy to children relieving overburdened healthcare systems [357]. From a companionship point of view, social robots are considered the future toy to offer social companionship to children in various settings¹.

In this section, we present a critical analysis of cHRI literature on social robots. Our goal is to discern what the current status quo in cHRI is. We think that social robotics technology is ideally positioned to support children’s collaborative play, but we want to identify responsible design opportunities mindful of children’s development and minimize ethical concerns.

We survey the cHRI literature focusing specifically on the proceedings of journals such as the HRI (now Trans-actions in HRI), the International Journal of Social Robotics, Science Robotics, HardwareX, Transactions on Human Factors in Computing Systems (TOCHI), and conference proceedings of the HRI flagship conference (HRI) the Conference on Social Robots, the conference of Interaction Design and Children (IDC), the International Conference on Robot and Human Interactive Communication (Ro-Man) and, the Conference on Human Factors in Computing Systems (CHI).

We survey the cHRI literature focusing specifically on the proceedings of journals such as the HRI (now Trans-actions in HRI), the International Journal of Social Robotics, Science Robotics, HardwareX, Transactions on Human Factors in Computing Systems (TOCHI), and conference proceedings of the HRI flagship conference (HRI) the Conference on Social Robots, the conference of Interaction Design and Children (IDC), the International Conference on Robot and Human Interactive Communication (Ro-Man) and, the Conference on Human Factors in Computing Systems (CHI).

¹ <https://www.scientificamerican.com/article/social-robots-play-nicely-with-others/>

2.2.1 *What are Social Robots?*

What are social robots, exactly? There are many definitions of social robots available in the literature, and they are continuously under debate [20, 18]. For this thesis, we define social robots as embodied artificial agents capable of social communication in human-like ways [39, 67]. The human-like design of social robots' embodiment, sensing, and behaviors arguably ease the interaction with children, leveraging existing mental models of human-human interaction [18]. Social robots are made of sensors, computers, and motors. All these components are usually assembled and encased in a human-like external hardware [18] that eventually constitutes the form of a robot. A social robot communicates verbally by replicating natural language and speech, nonverbally, by leveraging its body or sound and light modalities to communicate or combining the two. A social robot could establish spatial interaction by moving in the space or more static interactions by leveraging nonverbal and verbal communication. Social robots, especially those endowed with facial features or specific modalities (e.g., sounds) establish affective interaction, too, expressing human-like emotions and moods [183].

Social robots are different from digital technology, like computers and tablets, because of their embodiment [18, 227] and because they are designed and perceived as social actors [291]. In fact, unlike analog and digital technologies, social robots are endowed with or perceived as having agency, especially by children known to play along with the illusions of life [2, 3, 25]. Social robots are inherently a relational technology that establishes alterity relations: the robot is an "other" entity to build social-emotional relationships with [374]. It is not an object children manipulate with their hands to facilitate learning, like analog and traditional digital technologies. Still, social robots appear to impact children's education and socio-emotional learning positively, as demonstrated by the literature in cHRI [25, 225].

However, the relation properties inherent in child-robot interaction can be detrimental. Often, children's social interaction expectations are unmet, leaving children disengaged [26] if not disappointed. In extreme cases, children might develop aggressive feelings towards the robot [188], which might even lead to bullying [406]). Moreover, there are several ethical concerns. Research shows that personified, human-like robots influence children's judgment and influence children's behavior [379, 397]. While this influence can be beneficial, it brings about normativity [379], discrimination, and lack of inclusivity [61, 279, 321]: Who chooses which behavior is right or wrong for a child? What are the implications for children's development? What if children assume or conform to non-desirable behaviors? Who retains the control of the child-robot interactions?

Increasingly, researchers in cHRI address these issues by exploring new forms, roles, and pedagogical paradigms for social robots for children [7, 235, 7]. Designers are starting to opt for more abstract-looking robots

Tutoring Interaction Paradigm

A) ZAGA ET AL. (2015) THE EFFECT OF A ROBOT'S SOCIAL CHARACTER ON CHILDREN'S TASK ENGAGEMENT: PEER VERSUS TUTOR

B) THE ENIGMA PROJECT ROBOT. ©DE-ENIGMA PROJECT

Figure 5: The figure is illustrating two examples of tutoring interaction paradigms. On the left a) the work of [413] comparing peer to tutor roles in cHRI. On the right b) a picture from the Enigma project, exploring a robot peer as a near-future tool for autism education [307].

that resemble educational objects or toys both in their embodiment and roles. Social robots with less human-like behavior and human-like roles, or even simple robotic objects that show intent [299]. These robots shift social robotics applications for children from tutor-like paradigms to playful paradigms where children learn through play [235]. In the next section, we analyze the predominant interaction paradigms in cHRI.

2.2.2 Social Robots for Children: Interaction Paradigms

Among the many social robots applications for children, it is possible to identify two leading interaction paradigms: tutoring paradigms and playful paradigms. By interaction paradigms, we mean models of cHRI that describe who is interacting with who, with what scope, when, and how.

Tutoring paradigms (see Figure 5) focus on replicating various degrees the educational strategies and behaviors of tutors to integrate children's educations. Tutoring robots offer an intervention both for typically and non-typically developing children [69, 357]. The context of these educational interventions varies, from school to home-based education [306] and therapeutic centers [307]. Typically, interactions are one-on-one, a robot and a child or multi-party, but the former is the most prevalent literature. Within therapeutic contexts, adults might join the interaction to scaffold the activities.

The scope of tutoring robots is to deliver human-like personalized education to children, using machine learning (and in advanced projects AI) to adapt educational strategies to children [27]. Human-robot interaction research has demonstrated that tutoring robots have a competitive advantage

Playful Interaction Paradigm

A) LUPETTI ET. AL.(2017) ©OPEN ANIMATES

B) ©SQUIRREL PROJECT

Figure 6: The figure is illustrating two examples of playful interaction paradigms. On the left a) the work of [235] By playing with the robot Shybo, children could explore concepts related to various subjects. On the right b) the Squirrel project developed a robot to playfully tidy-up with children.

over virtual agents due to the higher degree of agency and social presence they deliver [227]. A tutoring robot's social presence vividly enables a social-relational aspect of learning that has been proven beneficial for children's learning [227]. Hence, tutoring robots are personified agents that take on an educational role with children. Tutoring robots are personified in a multitude of ways: from human-like puppets or dolls to zoomorphic forms [25, 208, 225]. Tutoring robots establish spatial, verbal, and nonverbal interaction. Verbal interactions, though, are the most prevalent. Tutoring robots explain, scaffold, ask questions, give answers and, provide suggestions. Often, tutoring robots interact with objects that can support the educational goal, like tablets [22] or educational objects. Whatever the form of the interaction, one common denominator is socially engaging with children by exhibiting human-like behaviors.

According to a recent review of Belpaeme et al. [27], tutoring robots take three social roles: teacher, peer and novice peer. These three social roles also represent the three main pedagogical paradigms of a tutoring robot. Robot teachers were the first tutoring robots to enter the classroom: they model their behaviors on teachers' behaviors and try to replicate their pedagogical strategies. The very first robot introduced like a teacher was Robovie [188]. In a seminal paper, Kanda [190] describes how Robovie autonomously delivered English language training to Japanese children. After Kanda, tutoring robots have been used for many educational applications. From learning mathematics [287] and languages [376] to learning how to manage chronic conditions such as diabetes. Unlike tutoring robot teachers, robot peers touch-upon the possibility to activate peer dynamics, proven beneficial to learning [413]. Robot peers offer tutoring like a more skilled, empathetic

child would do for another child [413, 209, 179]. Peer-like robots find application also with typically and non-typically developing children to learn socio-emotional skills, like empathy or emotional expressions [225, 307, 32]. Robot peers are applied to support children's motivation and self-esteem, too, for example, to nurture children's growth mindset [275] or children's curiosity [126]. A special kind of robot peers are robot novices that have a lower knowledge about a topic than a child has. Robot novices, like the Cowriter robot [156], flip the power in the teaching dynamics between the child and the robot leveraging what is known as the protégé effect. The child is teaching the robot, who admittedly expresses his incompetence on a particular subject and requests the child's support to learn about it. Robot novices aim to boost a child's confidence by providing the child with the opportunity to learn through teaching. Besides Belpaeme's taxonomy of tutoring robots [27], we identify other roles. Tutoring social robots can coach and mediate socio-emotional behaviors. For instance, tutoring robots mediate in children's play signaling when behavior is undesirable, and scaffolding collaboration [324]. Tutoring robots can serve as coaches to support children's cohesiveness in problem-solving tasks [354] or promote healthy eating choices [327]. On top of the pedagogical strategy and role, tutoring robots have demonstrated the potential to impact children's learning. Results from various research in HRI show that robots significantly impacted learning outcomes [225, 208, 287]. Social robots help children by explaining concepts [395], they support meta-cognitive strategies to deal with problem-solving tasks [287], they improve children's language skills [209] and support conflict resolution [324].

Tutor Robots

However, tutoring robots bring several challenges and concerns too. From a technological perspective, social robots are usually too expensive and not sufficiently robust to move out of laboratory settings into children's natural world. Social robots are rarely able to deal with the complexity of in-the-wild scenarios and rarely afford group interactions [225]. Thus, tutoring robots cannot be tested in ecologically valid settings, and long-term evaluations are hard to carry out (with notable exceptions, for example, [306]).

On top of the technical limitations, the most pressing concerns regarding tutoring robots are related to a mismatch between what a social robot can do, technically and socially, and what children expect the robot to do [25]. Human-like appearances, behaviors, and roles of tutoring robots make children ascribe much more intelligence and capabilities to the robot than the robot has [86]. The mismatch children experience diminishes the engagement or even distracts from educational activities [194]. This mismatch nurtures a feeling of deception and mistrust that, in the long run, is detrimental not only for the children's education but negatively impacts their understanding of agency and their morality judgments [188].

Another level of concern is related to the type of interventions tutoring robots have in educational settings. Social robot interventions focus on

formats of formal education [27, 69] on human-tutoring, coaching, and mediating strategies. By replicating formats, activities, and strategies usual in school education or therapy, tutoring robots might bring more challenges than solutions. Often, the interaction with a human-teacher is still preferable, as human-tutors outperform robotic tutors [193]. Teachers question a robot's ability to offer a meaningful learning experience and wish for a robot to take a complementary pedagogical role and focus on playful interaction [318]. By focusing on one-on-one tutoring of a child [69], social robots tend to neglect playful interactions with groups of peers, essential for children's development [300]. Another concern is related to the degree of control that children have in the interaction. By replicating the power dynamics existing with teachers, coaches, mediators, peer tutors, or novices, children might find it hard to retain agency on what decisions and actions to take [320]. Children conform with what a tutor robot says or asks [379], and they might be subject of suggestibility [396].

Learning from tutor robots' experience, HRI researchers increasingly explore new forms, roles, and pedagogical paradigms for robots in education. Increasingly, robotics applications to children's education shift from a tutor-like paradigm to a playful paradigm, opening new research and practice avenues.

Playful Robots

Playful paradigms (see Figure 6) focus on enabling playful interaction between robots and children (both typically and non-typically developing children). The focus could be educational or pure entertainment. Playful robots typically enable multi-party interaction but also can focus on one-on-one interaction. While tutoring robots tend to replicate the human form, roles, and behaviors, playful robots are less anthropomorphic. Focused on learning by doing and in playful interaction, playful robots are autonomous or semi-autonomous robots that take various forms. Playful robots capitalize on children's tendency (and people at large) to socially make sense of animate objects. Nonverbal interaction is usually predominant, as well as physical interactions.

Playful paradigms are not new in cHRI. The first commercially available robots for children were geared towards children's play, like the AIBO robot [189] or the Pleo robot. Nevertheless, recently there has been a surge of robots that enable playful learning by doing [272], to support creativity through play and storytelling [7], learning about computational thinking with a reactive playful robot [235] or playing with automated objects that nurture open-ended play [299].

Cellulo [272] for example, is a playful robot that blends-in with original educational activities and materials (pen and paper), enabling an interactive experience. Cellulo looks like a hexagon block with small spheres as wheels to afford locomotion and with colorful lights. While Cellulo can autonomously move around; children can also move it around, manipulating it like a piece of a puzzle. One of the applications of Cellulo, an astronomy game, Cellulo moves around on a map to indicate relevant content about

astronomy. At the same time, Cellulo can also be moved and directed by the child. Cellulo enables group interaction around learning materials as many children can interact with it at the same time. Similarly, YOLO developed by [7] is a playful robot aiming to foster children’s creativity in storytelling activities. YOLO has a rather abstract shape and few interaction modalities. It moves through locomotion, and it expresses itself with lights and movements. YOLO can be manipulated like a toy would and reacts to children’s play. Slightly more personified than Cellulo and YOLO, Shybo, developed by Lupetti et al. [235], is an open-source low-anthropomorphic robot that delivers playful group learning experiences and supports reflections about the robot’s ability to learn from example. Shybo reacts to children with a range of nonverbal behaviors, and it has been successfully embedded in teachers’ programs as an interactive storytelling object able to engage children in playful exploration of storytelling skills. Fizzy developed by [299] looks like an every-day object, a ball. It autonomously bounces and rotates to invite young children to get out of bed and move around through the hospital ward. While the ball tries to trigger a behavior, the children control the interaction initiating and ending contact as they please.

By adopting less anthropomorphic forms and roles, playful robots contrast the mismatch of expectations children experience interacting with robots. Simultaneously, children still imbue them with life-like qualities and make sense of low/non-anthropomorphic robots by translating their behavior into social terms. Therefore, a playful robot could still bring about anthropomorphism by the way they behave. As described by Edith Ackerman [3], playful robots appear to leverage the natural tendency of children to explore the agency of objects and toys and establish thing-like relationships typical of children’s play interactions which are potent enablers of learning.

Research on the effects of playful robots on children’s learning is limited, and little is known about the concerns with playful robots in the long run. Little is known about the actual long-term effects on children’s learning, and the actual feasibility of their deployment in the classroom at home or for therapy, as most of the platforms are predominately research-based. Moreover, notable technical challenges arise when robots move from one-on-one to one-to-many interactions like in intelligent playthings. Even more challenging is the ability to endow simple, low-cost, sturdy, and versatile robots with the computing power necessary to recognize children’s behaviors and appropriately engage with them in play. However, the playful-paradigm might be able to (i) enable embodied pedagogies and tangible learning, proven as beneficial for children’s development [12], (ii) favor inclusiveness bridging the interaction between typically and non-typically developed children by focusing on non-verbal interaction grounded in social play and (iii) integrate school curricula with topics that are not often covered by teachers, like socio-emotional learning, creativity, and playful learning.

2.2.3 *Social Robots for Children: Form and Behaviors*

Social robots come in many forms and communicate with children thanks to various behaviors [18]. By robot form, we mean the surface appearance of a robot. By behaviors, we mean the way the robot communicates with children to establish an interaction [70]

Physical Embodiment

Physical form is necessary for robots. Many scholars have discussed whether to consider the physical form of a robot solely or to have a more dynamic definition of form expanding to the notion of embodiment [70]. The embodiment hypothesis in social robots posits that [385]: *a robot's physical presence augments its ability to generate rich communication. The physical embodiment of social agents provides them with more modes of communication that can be used to convey internal states and intentions in more intuitive, human-like ways* [70] p. 264. In other words, what a robot looks like is a deliberate communication device to communicate to humans and, in our case, children. The physical form is also a cue for the affordances of a robot. Norman [263] (inspired by Gibson [119]) defined affordances as properties designed into objects that show users what actions to take, typically residing in the form of the object (e.g., a door handle affords the door to be open). However, as Hoffman and Ju pointed out [151], affordances depend not only on static properties or qualities but also dynamic behaviors (and nonverbal behaviors in particular) can cue a range of possible actions to users. Thus, a robot's physical form cues children about what the robot can or cannot do in interplay with a social robot's behavior.

As we have seen in the previous section, the status quo in cHRI are tutoring robots. Hence, the predominant social robotic form and behavior is human-like. Robots for children are designed to replicate human appearance with varying degrees. Human-like behaviors of social robots for children try to replicate the social cues, movements, speech, and natural language of humans, often with mixed results [18]. Within human-like robots, androids and humanoids most closely try to replicate the human ideal. These robots present features inspired by or replicated from the human body and leverage human modalities of communication [18]. Humans are the model of a social robot form and other existing creatures, like animals. Many robots feature a zoomorphic form, either replicating pets and animals we interact with every day (e.g., dog-like the AIBO robot [188]) or less realistic animals (e.g., dinosaur-like the Pleo robot).

Human-Like Robots

The critical premise of designing human-like robots is to leverage existing mental models of human embodiment and behaviors. However, as we have seen, human-likeness can be deceiving [25] or even create a feeling of repulsion [256]. Mori [256] with his seminal work on the Uncanny Valley explains that a human-like appearance of an entity other than humans is liked up to a certain degree of resemblance. When the resemblance is striking, people and children might experience dislike or repulsion. Designers in HRI strive to avoid the uncanny valley when designing tutoring robots. On the

other end of the spectrum reside robots for children with less human-like features. Robots are designed with low-anthropomorphic features [235, 105] or with non-anthropomorphic ones [6]. Increasingly, less anthropomorphic robots are design to resemble everyday objects, like [105] and [299]. These robots are designed with various degrees of abstraction. Abstraction is a key concept when analyzing a robot’s embodiment because different abstraction levels influence the human perception of a robot’s interaction affordances [70]. For example, an abstract robot and a robotic object share the same non-anthropomorphic metaphor; However, humans will perceive them as differently capable because of their different level of abstraction [70]. It is relevant to note that lacking human-likeness does not necessarily make a robot less engaging. First, humans (and children) tend also to anthropomorphize entities that do not look like humans. In her research, Eysel [18] explains that people have three psychological mechanisms to humanize nonhuman entities: (i) humans have the desire to see entities like robots as social actors; (ii) humans might turn a robot into a social partner due to lack of social connection; (iii) humans use their common sense knowledge about other humans to interact with robots. Thus, children relate to their anthropocentric knowledge to make sense of robots attributing intention, emotions, and human qualities to them. Simultaneously, they are hard-wired to interpret things that behave as having agency [142]. Designing for an appropriate interpretation of the robot’s behavior is thus one of the challenges of cHRI researchers.

Hard-wired to Attribute Agency

All in all, irrespective of the form or the behavior a social robot has or exhibits, the role of children’s expectations, interpretations, and understanding is vital. In the next section, we unpack and elaborate on the role of children’s expectations in cHRI.

2.2.4 *The Role of Children’s Expectations*

Humans are naturally inclined to imbue the “things” that surround them with the illusion of life. We are especially hard-wired to imbue “things” with agency, i.e., an actor’s capacity to act in a given environment and a personification to things that move and behave, “things” that are animate and respond to solicitations. The Computers-Are-Social-Actors (CASA) paradigm [291] has unveiled how people’s responses to technology like computers and robots are fundamentally “social”. When humans interact with these technologies, they apply human social rules, norms, and expectations.

Children and Agency

Children have a pronounced tendency to apply agency as they are still developing their abilities to distinguish animate from inanimate and read intentions [2]. Seminal work by Edith Ackerman [3, 2] has demonstrated that children systematically tend to explain agent (and robot) behavior in psychological terms. Ackerman considers children’s tendency to imbue everything that moves and behaves as beneficial with agency and personifi-

cation because it is a part of a necessary stage of development for children to learn what agency means playfully. Indeed, children often use pretense to play around with agency: inanimate toys and even invisible people can become children's friends.

cHRI leverages children's tendency to play with the illusion of life to enable robotic interventions in children's education. As we have seen, most of the robots designed to intervene in children's lives capitalize on human-like appearance or features, roles, modalities, and styles [27, 354, 51]. However, children play with the "*illusion of life*" [25] in ways that are unexpected by adults impacting children's ways of making sense of robots, the expectations they have of the interactions with robots, the way they make sense of the world, and, ultimately cHRI. When facing human-like robots, children have high-expectations of social interaction that often are not met, generating deception. Human-like appearances (e.g., eyes, mouth, arms, legs), behaviors, and roles deceive the children in ascribing much more intelligence and capabilities to the robot than the robot has [25]. Often, children are disappointed and lose engagement with the robot [27]. In other instances, children cannot explain the robot's behavior as it is not congruent with the human mental model that they apply [413]. Expectations of social interaction impact the potential long-term relationship too. It has been suggested that after sustained interaction, children might treat the robots more as a servant or object [188]. In turn, creating a robot like a servant might have carryover effects on the way children treat adults and other children [188]. Conversely, children might develop delusional relationships with social robots that could impact how they interact with peers. In extreme cases, when robots do not meet children's expectations, children's disappointment might be expressed in the form of bullying [262]. It is important to note that children's expectations of robots are also fueled by metaphors and narratives deriving from science fiction and the media.

Low/non-anthropomorphic robots do not leverage a human-like appearance, behavior, and role to establish relationships with children. Children still imbue them with life-like qualities and make sense of low/non-anthropomorphic robots by translating their behavior into social terms. However, expectations appear more balanced as there is a more vital adherence between the form of the robot and the function that generates a believable pretense of agency, avoiding deception.

When designing for cHRI, the way children explain and make sense of a robot's form, and behavior is fundamental to achieve the desired cHRI. Children's explanations of robot behaviors, as well as expectations, need to be taken into account. However, to the best of our knowledge, cHRI lacks design methods to account for children's expectations in the design process.

Designing Social Robots for Children

Current cHRI design methods are not geared to account for children's expectations in the design process. CHRI researchers and designers usually design robots for children. Hence, children are involved in the design process only as testers of the technology.

cHRI (and human-robot interaction) is a multidisciplinary field where engineers, roboticists, computer scientists, and designers collaborate. On top of the different approaches, the research practices of engineering and social sciences are predominant. While often user-centered, these practices consider involving users in the design process solely during the designs' formal evaluation. Researchers only understand the impact of the designed child-robot interaction partially and late in the design process, only during the evaluation. It is hard to understand how children interpret robot behaviors and perceive a robot [25]. Results for user testing are often surprising [194]. Children endow robots with animacy and agency in ways designers do not expect [86]. Current evaluation methods repeatedly fall short in accounting for children's experience because children find it hard to respond to surveys [225, 243]. Children have tacit knowledge about their experience with robots, but questionnaires, observations, and interviews usually are unable to tap into this knowledge [243, 90].

Co-design with Children

Recently, cHRI researchers are venturing into research design methodologies, such as co-design, that involve children early in the design process [7]. Co-design with children entails involving children in the design process to co-generate design solutions [90]. The co-generation process consists of generative activities tailored to children's abilities to tap into the tacit knowledge of children [88]. While there are first attempts to develop co-design methods to design robot behavior that communicates in human terms with children [7], established methods or validated rationales are not available. Collaborative design or co-design is a subset of participatory design in which designers and researchers work together with children on a design problem [330]. Co-design methods involve children either throughout the whole design process or during specific design iterations with the scope to ensure that children's needs and points of view on technology are met [102]. Co-designing with children stems from the idea that children are an entirely different user population with their own culture, norms, and complexity as they are humans in 'fast-paced' development. Within this perspective, children are treated as experts with special knowledge of their own experience of being a child'. Researchers in child-computer interaction (CCI) have involved children in various design partnerships levels: from the full involvement with design partnerships or co-researcher to a minimal involvement as tester [88]. The partnership level shapes the technology design process and impacts the technologies that are created [89].

All in all, cHRI is a young research field tied to the engineering and psychology tradition. Broadening the methodological perspective might help

mitigating the adverse effects of human-likeness and expectations mismatch leading to ethically desirable cHRI.

2.2.5 *Social Robots for Children: Conclusions*

This section introduced the field of social robots for children and critically examined its interaction paradigms and challenges. Through the perusal of the literature of cHRI, we identified two interaction paradigms: a tutoring-like paradigm and a playful paradigm.

Tutoring-like paradigms are the status quo in cHRI. Tutoring robots replicate the behavior and strategies of teachers, tutors, more knowledgeable or less knowledgeable peers to contribute to children’s formal and socio-emotional education. These robots have an undeniable positive effect on children’s learning [189, 208, 287], but bring notable concerns related to human-like tutoring roles, interventions, and behaviors. It is hard to maximize the social interaction a robot affords while minimizing children’s feelings of deception, mismatch of expectations, and ethical concerns with tutoring robots. On the other end of the anthropomorphic spectrum stands a playful interaction paradigm. Playful robots are abstract-looking robots that resemble educational objects or toys: Social robots with less human-like behavior and human-like roles, or even simple robotic objects that show intent [299]. They rely on more minor anthropomorphic cues to socially communicate to influence children’s behaviors positively. Arguably they are less prone to deception and cause children’s mismatch of expectations, but little is known about long-term effects.

No matter the form social robots for children take, there are some dynamics we should consider when designing for children: the role of anthropomorphism, expectations, and the tendency of children to blur the boundaries between animate and inanimate. These dynamics have a significant impact on cHRI, in certain instances even detrimental. However, we have learned that cHRI methods do not account for these dynamics yet, and broadening the methodological scope toward participatory practices such as co-design with children should be investigated.

Our analysis of the literature suggests that we should challenge the status-quo of tutoring interaction paradigms and consider the playful interaction paradigm. To this end, we need to acquire knowledge about the phenomenon of collaboration and collaborative play, we need to understand how to develop a playful interaction paradigm for collaborative play, and we need to break down the child-robot communication phenomenon to establish desirable interactions. The remainder of this chapter focuses on shedding light on the aspects mentioned above.

Figure 7: The infographic is illustrating how the socio-emotional level of collaboration influences the cognitive level of collaboration, that is the processes to coordinate intentions of doing something together, and the behavioral level of collaboration, that is the observable behaviors in collaboration.

2.2.6 Collaboration in Humans and Children

Collaboration is a crucial phenomenon of collaborative play. Collaboration consists of a series of actions two or more people undertake to engage in shared activities. Collaboration comprises sophisticated motor, cognitive and social skills found to be unique to the human species [361].

According to Bratman [37], collaborative activities (that the author calls joint cooperative activities) have three characteristics that set them apart from social interaction in general: "(1) *they are mutually responsive to one another*, (2) *there is a shared goal in the sense that each participant has the goal that we (in mutual knowledge) do X together*, and (3) *the participants coordinate their plans of action and intentions some way down the hierarchy – which requires that both participants understand both roles of the interaction (role reversal) and so can at least potentially help the other with his role if needed*" [365, p. 680].

To engage in the unique form of social interaction that is collaboration, humans developed cognitive representations that enable them to behaviorally engage in a shared activity and eventually to collaborate [273]. In other words, humans have developed social cognition, several cognitive processes that enable, support, and guide our social interactions in general and our collaborative interactions in particular.

Tomasello [365] defined the cognitive processes underlining joint activities among humans as social engagement. Collaborative interactions require a particular social engagement. To engage in collaboration, one must align

Social Cognition and Social Engagement: the pre-condition to collaboration

the self's cognitive process to form a representation of a shared goal. Nevertheless, to engage in collaboration, it is also necessary to take the perspective of the other in order to understand and coordinate the differing but complementary roles in the joint activity [365]. Children reach the required level of social engagement to engage in collaboration after only 12-14 months. Tomasello [361] identified three social engagement stages that are typically developing humans go through dyadic engagement (0 to 9 months), triadic engagement (9 to 12 months), and collaborative engagement (12 months onward).

In *dyadic engagement*, a child can interact with and respond to whatever agent (i.e., another person, an animal, or else) is animate (i.e., moves autonomously), thus dyadic engagement. In dyadic engagement, the child's behavior constitutes expressing emotion and engaging in turn-taking. An example of dyadic engagement is an infant laughing after a parent uses movements and voice to play peek-a-boo with the infant.

In *triadic engagement*, a child starts to understand what it means for an agent (i.e., another person, an animal, or else) to be goal-directed, to do an action with a deliberate scope, and the child coordinates not only with an agent but also with objects instrumental for the goal, thus triadic engagement. With this knowledge, a child can interact with the agent that has a goal. To do so, a child monitors the partner's goal-directed behavior to jointly engage with him or her and coordinates with objects that focus on the goal-directed behavior of the partner and toward the relevant outside objects. An example of triadic engagement is a child that wants to play "fetch" with a dog.

In *collaborative engagement*, a child interacts with an agent towards a shared goal. To engage in an activity with a shared goal, the child and the agent need to coordinate actions, attention, and intention. Both child and agent represent the shared goal cognitively; they plan to take their role in the interaction to reverse the role or help with the role if necessary. An example of collaborative engagement is a child solving a puzzle with another child.

The stages of social engagement described by Tomasello [365] provides the frame of reference to understand the social cognition apparatus that enables collaboration in humans. However, collaboration not only consists of cognition, but it also entails behavioral and socio-emotional aspects. Behavioral and socio-emotional aspects of collaboration depend on socio-emotional and group dynamics that often require regulation and support.

At a *cognitive level*, engaging in collaborative activities underline collaborative engagement and *shared intentionality* [365]. The latter is a mutual understanding that all the parties involved have a shared experience, a collective awareness of each other's presence and actions (joint attention), and a willingness to influence each other's goal-directed, emotional and cognitive states. Tomasello [365] has further defined shared intentionality as the human ability to read each other minds to coordinate actions and achieve goals. In other words, shared intentionality is the ability to cogni-

tively representing another's intentions to guide what actions to take and what attitudes to have in a shared task. Shared intentionality is the key dynamic of collaborative engagement that enables humans to engage in collaboration.

At a *behavioral level*, collaboration involves several observable behaviors that express the underlying cognitive and social processes [361]. Gaze behavior to regulate and redirect each other's joint attention to people and objects, object-manipulations (e.g., picking up, moving, and pushing objects) to act toward the common goal, other movements, and gestures to coordinate and synchronize with each other, and communication (verbally and nonverbally) about actions to take or not to take or to express emotions related to the activity and negotiate actions and decisions in the activity. The observable behaviors that people exhibit in collaboration not only depend on the people's cognitive processing related to shared intentionality [365], but first and foremost depend on socio-emotional processes [300].

At a *socio-emotional level*, collaboration entails interpersonal (i.e., the effects of one individual's socio-emotional behavior on the other's behavior) and group dynamics [249] that determine much of the actions and emotions expressed during collaboration. Collaboration is regulated mainly at a socio-emotional level. The outcome of collaboration both at the task (e.g., whether people succeed to realize the goal they had in mind) and social level (e.g., whether people successfully resolved the conflict and maintained prosocial attitudes) depends on how people regulate their interpersonal and group dynamics.

*Interpersonal and Group
Dynamics*

Collaboration in itself is mainly an *interpersonal* prosocial dynamic which comprises of different *prosocial behaviors*, such as helping, sharing, comforting, and co-operating [365]. Prosocial behaviors in collaboration are mediated at the interpersonal level (i.e., the effects of one individual's prosocial behavior impact another behavior) and group level. In other words, how people prosocially behave towards one another in the activity and before the activity (e.g., *reciprocity*) [283], the attitudes that people have for one another (e.g., people tend not to help individuals they deemed as antisocial [396], or to collaborate more when they feel they are part of the same group [75]) and our relationships (e.g., friendships, kinship, antagonism), [97]. The regulation of interpersonal prosocial dynamics is *de facto* a process of *moral reasoning* [251]. In moral reasoning, individuals, using logic and self-reflection, determine why a specific act is right or wrong to do. Therefore, people morally reason about when it is 'ok' to share or to help one another or take another's perspective to understand emotional and social states and take actions accordingly. In collaboration with people, it is not sufficient to monitor each other actions to coordinate actions and intentions (that is what happens at the cognitive level in shared intentionality). However, people need to assess the interpersonal prosocial dynamics to guide their actions [96].

Collaboration is not done in isolation. By definition, at least two individuals interact with each other while collaborating. In many instances, more than two individuals engage in collaboration. When more than two individuals interact in collaboration, group dynamics arise. *Group dynamics* play a role in regulating collaboration. For instance, when people consider themselves as part of a group, they tend to prefer and be more prosocial among group members [283] (i.e., in-group) and less towards other people (i.e., outgroup).

Group norms, rules or behavioral guidelines that reflect expectations of how group members should act and interact, often implicitly emerge in a group and have an impact on collaboration [249]. While adults have an ingrained understanding about how groups should work together and behave, children need to be exposed to collaboration (and particularly to collaborative play) to be able to infer more general "ground rules" of what collaborating in a group entails: *"the idea that members should be loyal to their groups, that groups will act to enforce their own norms, and that people may be judged not just use of the group they belong to but because of the way their behavior or attitudes relate to differences between their own and other groups"* [416]. Often norms are derived from the relationships established while collaborating with the group: people may alter their behavior to publicly match the group norm, mirroring each other's behaviors or attitudes. Other times norms are established by simple attainment to each other's way of interacting, promoting prosocial and reciprocal dynamics. While people tend to like group members that adhere to the norms more and are prosocial, they tend to judge negatively members who do not follow the norms (i.e., the black sheep effect) [244].

Groups can be cohesive (i.e., the ability to think and behave like one) [155] or divided in collaboration. People can take sides or divide into subgroups when collaborating. The seminal work of Simmel [329], for example, unveiled how collaborating in a triad could lead to subgroups, thus creating imbalances in the collaboration: excluding people in the group or dominating the decision making, causing conflict and less prosocial behaviors. During collaboration, people also experience *interpersonal conflicts* [319] arguing about either interpersonal or object-oriented issues. Socio-emotional strategies are needed to deal with the conflicts and regulate collaboration [248].

Regulating collaboration

The behavioral and socio-emotional aspects of collaboration need to be regulated to guarantee optimal collaboration in terms of task performance (i.e., how the shared task is executed) and interpersonal and group interaction. In childhood, promoting interpersonal prosocial dynamics, such as helping and sharing, and supporting conflict resolution is key to supporting collaboration [283, 300, 342]. Collaborative play could serve as a test-bed to promote prosocial behavior and resolve conflict in a playful and child-centered fashion.

In sum, collaboration consists of joint activities between two or more individuals in which goals and intentions are understood and shared. Collaboration underlines the cognitive ability to engage collaboratively and observable behaviors (e.g., gaze, object manipulation, and verbal/nonverbal communication). Collaboration is achieved through internal cognitive processes of shared intentionality (collaborative engagement), but it is externally regulated by socio-emotional dynamics, especially by interpersonal prosocial dynamics (e.g., reciprocity of helping or sharing) and group dynamics (group norms and conflicts). Promoting prosocial behaviors and resolving conflict, bearing in mind group dynamics, enables the regulation of children's (and adults) collaboration and supports positive collaborative interaction.

2.2.7 Prosocial Behaviors in Collaborative Play

People and children often perform actions to benefit others: they are examples of *prosocial behaviors* [313]. Prosocial behaviors are interpersonal and social actions [97]. There are many ways to act to the benefit of others: At the interpersonal level (i.e., between two persons or in a small group), actions such as *sharing*, *helping*, co-operating, and comforting are prosocial behaviors. At the societal level, actions like volunteering and co-operation (e.g., co-operation between states or companies) are examples of complex prosocial behaviors [313]. This dissertation focuses only on prosocial behaviors occurring at the interpersonal level during collaborative shared tasks in collaborative play: helping and sharing [388].

The phenomenon of engaging in prosocial actions constitutes of three components: (i) the ability to recognize that another person is having a problem, to take their point of view and perspective; (ii) the ability to determine the cause of that problem; and (iii) a motivation to intervene to solve the problem [91]. Therefore, benefitting another (being prosocial) involves intervening when they are faced with a negative experience [97]. For example, a father folds clothes on a table while a child is playing on the floor. The father drops a dress from the pile of unfolded clothes on the floor outside his reach (problem). The child notices (takes the father's perspective), she realizes that the father has a problem, a clean unfolded dress should not be on the floor, and the father cannot reach it, so it should be picked up and motivated by witnessing the distress of her father, she picks the dress up and hand it to her father, thereby helping him. While children up to two years old need to recognize an overt problem to intervene [91], adults are motivated by imagined or implied distress and engage in prosocial behavior even in the absence of direct perception of needs [313].

Intervening in other's problems, needs, and distressing situations is costly. Being prosocial is costly of time, energy, and effort and not always have a clear reward. So, why are people prosocial? What are the motivations to be prosocial and help?

*Why are people
prosocial? Motivations*

Theories of evolution suggest that – to a certain extent – humans have a natural disposition to be prosocial [361]. After all, helping each other and sharing and other prosocial behaviors have an evolutionary advantage despite their costs: prosocial and stick together have more chance to survive. Therefore, the ability and tendency to be prosocial to one another is ingrained in humans [313]

Although humans have a natural disposition to be prosocial, there are also egoistic, altruistic, and social motivations.

Egotistic motivations can be described in an arousal-reward model. Acting prosocially relieves (i.e., rewards) the negative arousal caused by seeing another person in need. Egotistic motivations are the first that emerge in human children between 0 and 2 years old and can still be present in adulthood.

Altruistic motivations are caused by empathy. Empathetic concerns drive a person to help another without direct reward. Empathetic concerns are highly dependent on a person's ability to take perspective and express empathy.

While egotistic and altruistic motivations are regulated at the personal level, *social motivations* are mediated by social interactions and norms thereof. Social motivations of being prosocial are dictated by norms of co-operation, helping, or sharing within a group of people. The norms can be established internally, by the group, or externally by society. When established internally, the norms depend on the way the people behave with one another and their social reputation. Reciprocity of actions, being recognized to be a prosocial person mediates motivation to help: people reason morally whether to help.

What does it mean to help? How do children decide to help each other? As we have seen, children begin to help from very early on in their life, driven by mainly egotistic and later altruistic and social motivations [390]. Help is somewhat of a costly behavior: one intervenes to support an individual's actions or to alleviate a situation. In some instances, helping, despite being costly, can support mutual gains as it might establish collaboration.

At a general level, children's emerging social-cognitive capacities enable them to decide when and how to intervene, but children may learn to help because they imitate other people's helping behaviors [313].

Children during infancy help others to a large extent based on intrinsic motivation, both egoistic and altruistic [390]. However, children become selective in their helping and sharing quite soon as well and especially when they enter a more elaborate social network (e.g., school) and more elaborate collaborative interactions (such as collaborative play), motivating their prosocial behavior socially [365, 283]. Thus, children prefer to be prosocial with "nice" over "mean" individuals (moral reasoning), they reciprocate individuals that have helped or share before, they embrace social norms of helping and share and co-operate when interacting with prosocial peers [97].

Sharing is a prosocial behavior exhibited to relieve another's unmet material desire or need. When compelled to share, a person wants to rectify

an unequal distribution of resources. Sharing is a fairly costly behavior, as one person gives up a resource that belongs to him or her [313].

Young children share with others to a large extent based on an intrinsic motivation aimed at others' well-being, therefore mainly for egotistic and altruistic motives. Typically children share when a clear clue of "need" is expressed [97, 390], including verbal or nonverbal communication and affective displays. Over infancy and childhood, children express a tendency to share resources equally. Equality becomes the norm during the school-age, especially in collaborative situations.

Sharing becomes selective. Despite children's tendency to be fair and equal, reciprocity, moral judgment on another child's behavior play a role in mediating sharing.

*Reciprocity of Helping
and Sharing*

Reciprocity is crucial to mediate prosocial behaviors, especially during collaborative interaction, such as collaborative play.

Reciprocity can be direct or indirect. *Direct reciprocity* is based on one or more interactions between two children. It can be defined as '*reciprocating the prosocial behavior I have received from you*' [266, 270]. Being the recipient of a prosocial behavior supports the emergence of direct reciprocity (i.e., anyone who receives a prosocial behavior is likely to reciprocate and consider the "giver" as a helpful person worthy of reciprocating) [391, 375, 283]. *Indirect reciprocity* is based on a children's ability to evaluate others according to their prosocial behavior towards a third party in repeated interaction in groups. Indirect reciprocity supports the emergence and development of cooperative interaction, promoting the choice to work together towards a common goal. It can be defined as 'I help you because of the help you have given to others in the task and previous encounters' [117, 265, 192]. Indirect reciprocity can be *upstream indirect reciprocity* (i.e., if the recipient of a prosocial behavior helps another child) and *downstream reciprocity* (i.e., the child who exhibited prosocial behavior towards another participant becomes the recipient of a prosocial behavior). Indirect reciprocity is more likely to develop over time, and it is likely the byproduct of an individual's reputation in a task and beyond (i.e., helpful, cooperative).

Children tend to reciprocate direct and indirect acts of giving by others, engaging themselves in prosocial behaviors and reward those who give to others. Reciprocity influences the emergence of prosocial behavior immediately, or in other instances, basic prosocial behaviors emerge first, and reciprocity begins to mediate these behaviors later. In any case, children have a basic spontaneous tendency to help and share without taking reciprocity into account, which then becomes mediated by reciprocity later in development, especially when starting to engage in collaborative interactions and collaborative play. Children in infancy are mainly altruists and become more selective as they enter the social world. Reciprocity not only fuels collaboration and promotes prosocial behavior, but supports the establishment of prosocial norms, thereby motivating children to collaborate and be prosocial.

*Promoting prosocial
behaviors in
collaboration and
collaborative play*

As we have seen, interacting with prosocial peers promotes the development of dynamics, norms, and beliefs about how prosocial behavior should be used to guide children's prosocial behaviors with others in the long term. For example, Fabes and colleagues [101, 99] found that exposure to prosocial peers was related to increased prosocial behavior a year later.

It appears evident that children tend to reciprocate a prosocial child to them or children whom they observed helping a third party or each other. Children will judge it fair to share with a child shared in the past or that helped and co-operated. These reciprocal dynamics support the development of children's prosocial behaviors and regulate prosocial behavior in interactions.

Children learn when and how to be helpful during playful object-oriented interaction with peers. The mere exposure to the action of helping or sharing of one child to another in a game leads to (i) direct reciprocity from the child that was helped (ii); indirect reciprocity from other children that may have witnessed that the child was helped; (iii) more tendency to be prosocial in the group and towards the helper in the short and long term [97, 283].

To conclude, prosocial behaviors are actions to benefit others, such as helping and sharing, that are elicited by recognizing a state of need of another person (either instrumental need or material need) and motivated by egoistic, altruistic, or social motives. Social motives are driven by assessing a person's previous actions or behaviors and by social norms. While children have a natural tendency to be prosocial, they become more selective as they grow and interact in the social world. Reciprocity, both direct and indirect, mediates much of helping and sharing and supports prosocial norms. Interacting with prosocial peers promotes the development of dynamics, norms, and beliefs about how prosocial behavior should be used to guide children's prosocial behaviors with others in the long term. Prosocial dynamics are critical in collaboration and collaborative play: promoting prosocial behavior in collaborative play means acting on children's social motives and reciprocal dynamics.

2.2.8 *Children's Conflict in Collaborative play*

When interacting with each other in collaborative play, children experience conflicts [319]. Conflicts in childhood are disputes involving pairs of children or groups of three or more [323] arguing about either interpersonal or object-oriented issues. When children conflict, they cannot get what they want: they could want an object or change another child's behavior. In either case, this desire is not fulfilled because another child is opposing it or is arguing against it. Conflicts vary in nature depending on the interaction setting [248]. Unlike aggression, conflicts serve an important developmental function. Experiencing conflicting interactions in collaborative play supports the development of critical skills to deal with arguments and regulate socio-emotional competence [319, 127].

Scholars [298, 319, 217] have identified the structure and unpacked the main features of children's conflict: first, an arguable event and initial opposition occur, thus a conflict starts with *issues* [319]; then, *strategies* arise to regulate the conflict [248]; ultimately, the conflict comes to an end and generates *outcomes*. The conflict's outcomes have effects both on how the conflict is resolved and on how children will keep on interacting with each other [319, 298, 97].

Conflict issues are numerous in childhood. Scholars in developmental psychology [319, 248, 217] have observed that disputes about possessions of objects and playground control are usually predominant in infancy. In middle childhood, conflicts are predominantly relational (i.e., friendship, moral rules, controlling participation in joint activities). Like in collaborative play, conflicts revolve around the regulation of collaboration, like when to give or take, when to help or when to share resources, thus mediating helping and reciprocity behaviors.

*Conflict Regulation
Strategies*

Overt behaviors such as give and take of resources among children during tasks underline strategies to regulate collaboration [97, 284]. Among many dynamics, prosocial dynamics regulate conflict resolution [319] and influence reciprocity behaviors [283]. Children resort to multiple strategies to deal with conflicts [217, 218].

Like adults [371, 158], when children use *strategies to go towards one another*, they use *prosocial strategies* in order to resolve a conflict. For example, children decide to share objects as opposed to fighting about them [248, 319]. When children invoke *strategies to go against one another*, they make use of *coercive strategies*, such as taking away objects to stop the argument [248]. Another set of strategies children use is invoked to *go away from one another*, that is, to not intervene directly in the conflict. Strategies of *non-intervention* could also lead to seeking adult intervention, shifting the conflict from peer interaction to adult-child interaction [319].

Conflict Outcomes

Conflict outcomes are of four types: (i) unresolved children drop the issue, (ii) mediated, somebody, suggests or imposes a resolution, (iii) submission of one child to the will of another, (iv) a mutually agreeable solution [218, 217, 319]. Strategies play an essential role in leading to one of the above-described outcomes. Children modify their actions concerning the experienced strategy, leading to one of the outcomes. Moreover, the strategies employed to deal with the conflict also influence how children will interact with each other after the conflict is over. Therefore, an important aspect to consider when intervening to support children's conflict resolution is favoring the most desirable conflict outcome and choosing a strategy that might positively impact the subsequent peer dynamics.

*The impact of Conflict
Resolution Strategies*

Peer interactions offer a test-bed for children to learn how to negotiate, take turns, share and persuade one another to resolve conflicts [319]. Strategies and related outcomes of children's conflicts thus impact the socio-emotional dynamics of peer groups, which ultimately extend beyond the boundaries of a specific dispute.

The main factor that influences peer group dynamics in a conflict interaction is the interpretation of each other behaviors [298, 319, 217]. Children consider each other's prior behaviors to determine how to react and interact with each other in the conflict and beyond. The interpretation of the underlining intention of a strategy to deal with a conflict plays a pivotal role. On top of the influence of existing relationships among peers and the role of context, the structure of a conflict (how a conflict unfolds) and the conflict resolution strategy's interpretation have the most significant impact on collaborative play.

More than one strategy could lead to a conflict outcome, but there is a qualitative difference in the effect of collaborative play strategies. For example, coercive strategies could lead to outcomes such as submission or dropping of the conflict. However, at the same time, one or more peers' coercive behaviors might negatively influence the peer group bringing about, in subsequent interactions, less prosocial behaviors, negative interpersonal relationships in the group, or issues of peer dominance. All these effects can hinder collaboration outcomes and dynamics.

Conversely, a prosocial strategy exhibited in a conflict leads to future prosocial behaviors in interactions and establishes a positive interpersonal relationship among peers (children like children who help more). As we have seen in previous sections, [97, 267, 284] when children are exposed to simple prosocial actions of peers, such as helping and sharing, these actions influence the direct and indirect reciprocity of these prosocial actions in the children ([267]). Moreover, children will be more likely to keep interacting with prosocial peers that helped or shared, favoring bonding and friendships. Exposure to prosocial peers is related to long-term benefits such as increased prosocial behavior a year after the interaction [97].

*The role of Individual
Differences and
Affiliation*

The strategies used to resolve a conflict are not the only factors influencing conflict resolution and collaborative play. Developmental research [182] has stressed the role of individual differences and affiliation on the propensity of resolving conflict amicably. Children that can take the perspective of another child are usually more inclined to resolve conflict in an agreeable way [93, 182]. Therefore, *empathy* plays an essential role in determining conflict outcomes and must be taken into account. At the same time, when children show a highly developed level of empathy, it could also turn out not to be in the interest of resolution of conflict, but in their interests, to achieve their ends [94]. *Affiliation*, the bond we have with one another, is another source of influence on children's conflict resolution [182]. Children tend to protect existing friendships, and they lean towards positive conflict outcomes when conflicts arise among friends [141]. Therefore, it is important to take individual differences such as empathy, affiliation, and friendship when investigating children's conflict resolution behaviors.

In sum, children experience conflicts when interacting in collaborative play. While harmful, conflicts have a role in children's development: conflicts

“train” children to deal with issues and resort to positive outcomes. In the next section, we delve into play and collaborative play.

2.2.9 Play in Childhood

Play is an ever-changing process developing over the life of children [114]. Children, as young as baby infants [124], play with objects, with each other, and with parents to discover the world around them, to master control of their bodies and ideas and ultimately, to develop socio-emotional skills [280].

What is play

Despite being very easy to observe, defining play is hard because it is a *multi-dimensional phenomenon* unfolding in a *spectrum of activities* [418]. Play has often been defined as a series of voluntary child-led activities defined by the child [114], but recently also adult-led activities have been included in the spectrum of play [418]. Play does not hold a prescribed goal, but it is an activity where the process is more critical than the outcome [300]. Think about two children building with blocks: it does not matter whether the resulting construction has a purpose, whether it will hold up for long. The mere activity of using the blocks to build something is enough for them. Thus, play is holistic, flexible. Play also nurtures a positive emotional state in children: children are engaged and find play meaningful and joyful.

Types of Play

What exactly does it mean for children to play? *Play* encompasses several children’s observable behaviors. Play behaviors are frequently interpreted as *physical play*, when play takes the form of physical activities using gross and fine motor skills, *social play*, when play takes the form of interaction

<i>Play Type</i>	<i>Activities</i>
Physical	Gross and fine motor activities e.g., hide and seek
Object-Directed	Exploration of objects and toys e.g., building a tower
Social Play	Together with peers and adults e.g., playing with blocks together
Symbolic Play	Make-believe with objects e.g., playing with a banana as if it is a phone
Pretend Play	Make-believe, role-play e.g., Play the astronauts
Guided Play	Guidance from adults e.g., playing with the microscope
Co-opted Play	Initiated by the child, directed by adults e.g., building a tower, adults re-direct to other
Games with Rules	Activities with rules e.g., playing with a board game

Table 2: The table is showing the many forms play could take: on the left types of play, on the right the activities related the type of play. Types of play are to be understood in a spectrum, often overlapping one with the other.

between children and adults or between peers, or *object-directed play*, when play takes the form of interaction with objects (e.g., toys or everyday objects), or *pretend and symbolic play*, when a person or object represents something else not necessarily existing in the world [280, 232]. Social play, object-oriented, and pretend play cross each other's domains: object-directed play with a toy could also be a form of social and pretend play or vice versa. Recent developments in the study of play [418, 109], have highlighted how educational play, either in the form of guided activities, games, or co-opted play, should be considered in the play taxonomy. Table 2 summarizes play types, giving an example of activities for types of play.

According to Piaget, play and related play types evolve with the developmental stages of the child. Piaget proposed four stages of cognitive development which reflect the increasing sophistication of children's ability to think and make sense of the world they are in: the *sensorimotor stage* (the child explores the world with his/her senses, from birth to age 2), *pre-operational stage* (the child can make sense of the world with language, memory, and imagination, from age 2 to age 7), *concrete operational stage* (the child uses logical thinking and some abstraction to make sense of the world, from age 7 to age 11), and *formal operational stage* (the children know how to logically use abstraction to make sense of the world, age 11 and older). Piaget posited that the way children play evolves within the development stages from more sensorial types of play to more abstract types of play. Recently, the link between play types and development is considered more flexible [418].

Play and development

Play not only evolves in line with children's development, but it also has an impact on children's cognitive and socio-emotional development [281, 382]. The two main theories that describe the relationship between play and development are the ones articulated by Piaget [281] and Vygotsky [382], while Parten's [277] was the first to systematize how children play with each other.

For Piaget [281], play is the "*cognitive-developmental gym*" of the child. Through play, children practice what they are learning about the world; they train cognitive, socio-emotional, and motor skills that they have acquired. Piaget sees play as a reflective process of learning, but not as a moment to gain more knowledge. Children apply the models, frameworks, and social attitudes that they have learned and fit it to play, which is a process of assimilation in Piagetian words. Conversely, Piaget defines learning new information as accommodation, a process of transformation of what we know already to new information, which Piaget does not consider part of the play.

Play as socio-emotional
learning

In contrast, Vygotsky [382] considers *play as the locus of learning*. Children not only practice what they already know, they also learn new things. Especially, playing with others – peers or adults – is an activity that supports children's development of socio-emotional skills. Post-Vygotskian researchers [33] have connected almost all the forms of play to Vygotsky's

theory of play, and they have linked play to another Vygotskian construct, the *Zone of Proximal Development* (ZDP). According to Vygotsky *a child learns new things about the world when the child plays with peers or adults*. The ZDP refers to what a child can do without help and what he could potentially achieve with an adult or a more skilled peer's guidance. Thanks to guidance and exposure to the interaction with peers and adults, the child retains cognitive and socio-emotional knowledge that the child will then master independently. Overall, the Vygotskian theories consider play with peers and adults not only a fundamental activity for formal learning but also *socio-emotional learning* of how to behave with each other.

Social Play

As highlighted by the Vygotskian tradition, social play is the type of play that is key for developing socio-emotional competencies. Parten [277] was one of the first to study the social interactions in play, defined as social play. Parten systematized play into stages depending on the type of social interaction during the play activity. The level of social involvement between individuals is increasing from stage to stage: *Solitary play* (0-2 years old), when children play by themselves with their toys, *Parallel play* (1-2 years old), when play runs side by side with other children, *Associative play* (3 years old) children truly play with others forming little groups, *Onlooker play* (from 2 years old), the child watches others at play but does not engage in it, *Cooperative play* (starts at 4 and half years old), children playing in groups as they did in associative play, but now the children demonstrate division of labor, whether working on a group project or cooperating to attain a common goal.

Broadhead [41] built on Parten's taxonomy of social play but brought it a step further. Broadhead considers social play as a continuum with four levels: associative play, social play, highly social play, and cooperative play. Levels are assessed depending on the level of reciprocity and communication between children achieved in each stage. Within Broadhead's perspective, social play is the principal locus of social skills and problem-solving skills learning.

While Piaget's classical theories, Vygotsky, and the stages of social play of Parten have focused on open-ended play activities, recently, the scholarship has started to embrace social play with rules and guidance (i.e., games, playful learning activities) as part of the play phenomenon. Zosh et al. [418, p. 9] proposes a '*multidimensional definition of play that creates a spectrum of play opportunities from free play through guided play to games and then playful direct instruction (a form of direct instruction with minor playful elements to try to keep children engaged)*'. Following Zosh et al. [418] definition, a child's social play experience constitutes the following dimensions: who initiates play, who directs the play, and whether there is an explicit learning goal in play. The spectrum of play, therefore, goes from playful activities initiated and directed by the child without explicit learning goals (i.e., *free play*) to ones initiated and directed by the adult with an explicit learning goal (i.e., *direct instructions*). In between, there are play activities with a learning goal

initiated by adults and directed by the child (i.e., *games and guided play*) and play initiated by the child and directed by the adult (i.e., *co-opted play*).

To conclude, play is a multidimensional array of activities children and adults engage in master and learn a wide array of skills while experiencing joy. Within the various types of play, social play enables children to engage in playful social interaction, thereby learn, master and perfecting socio-emotional skills. Children engage in various play and social play depending on their age and developmental stage, with collaborative play predominant after five years of age. Social play (and play in general) is currently understood as a spectrum that includes structured and playful learning. It enables researchers – amongst other things – to focus on a broader array of playful activities that could support formal and socio-emotional learning, thereby opening avenues to the study of new technologies for play, like computer applications, games, interactive toys, and robots.

2.2.10 Collaborative Play in Childhood

Children play on their own, but they also engage in playful activities with parents, siblings, friends, or classmates [300]. When playful activities with others are sociable, joyful, and cooperative, children engage in collaborative play.

Defining Collaborative
Play

Collaborative play is a type of social play in which more than one child (or an adult) is engaged in an enjoyable shared task/activity, usually with common or shared goals [41]. Collaborative play can happen in dyads (two children or one child and one adult), triads (three children or children and adults), or small groups. Activities might vary from open-ended and object-oriented play (e.g., building constructions together) to game with rules (e.g., playing a collaborative board-game). From informal guided-play (e.g., a child and adult making a sandcastle together) to pedagogically-oriented guided play (e.g., playful collaborative tasks at school). Irrespective of the activity, collaborative play always entails a degree of collaborative behaviors among children.

The collaborative play exposes children to others' perspectives and behaviors, thereby scaffolding their own and their friends' learning experiences, including socio-emotional skills learning [300].

Collaborative Play and
its impact on children's
development

Developmental [97, 73], social psychology [71, 17] and education [294, 232] research shows us how children learn social skills better *by doing* activities while playing with other peers, by experiencing interactions, actions and effects thereof rather than from instruction, reinforcement or scaffolding.

Through collaborative play, children pick-up from other children when and how to be helpful, share, and co-operate during playful object-oriented interaction with peers, thereby learning how to regulate collaboration. For example, the mere exposure to the action of helping of one child to another in a game leads to (i) direct reciprocity from the child that was helped; (ii) indirect reciprocity from other children that may have witnessed that the

child was helped; and (iii) more tendency to be prosocial in the group and towards the helper in the short and long term [97, 97, 283]. Especially in play, prosocial or group dynamics are mainly regulated through actions in play (with objects or not) and nonverbal behaviors.

*Why Collaborative Play
is Important*

However, why is it essential to promote collaborative play? Are not children already learning by themselves just through interaction? Even when potentially able to collaborate, children, especially when entering extended social networks, like schools, poorly participate in collaborative activities and have socio-emotional issues [300]. Playing together in groups does not mean children will automatically co-operate, help each other, share resources and avoid conflicts [31]. While able to collaborate and be prosocial at a behavioral and cognitive level, at a social level, children might encounter difficulties, which can have relevant consequences on their *socio-emotional development* and skills thereof [260]. Social loafing (i.e., tendency to withdraw from collaboration), free-riding, issues of unbalanced dominance, exclusion from the collaboration, and anti-social behaviors (e.g., harassment, distress, bullying) are examples of negative behavior which arise when children face difficulty in collaboration because they are unable to resolve conflict or to resort to prosocial behaviors [260]. The reason for negative behaviors in collaborative activities varies: group's interpersonal dynamics could be troubled due to dysfunctional communication, misinterpretations of behavior, overruling or undermining of other's actions, personality clashes, or frustration [31].

Overall, collaborative play is a type of social play in which children and adults are engaged in shared playful tasks. Collaborative play is the test-bed of collaboration and dynamics thereof and positively impacts children's socio-emotional development. While happening naturally among children, collaborative play is not often effectively performed by children, and occasions to engage in collaborative play are slim the more the children are involved in the elementary school system. By promoting collaborative play activities at school or home, we can enable children to train the social skills needed to collaborate, deal with conflicts, and stimulate prosocial behaviors.

2.2.11 *Children's Collaboration, Prosocial Behavior and Collaborative Play: Conclusions*

In this section, we learned that the *social level of collaboration* has an impact on the social (prosocial behaviors, conflict resolution) and task dynamics (task outcomes) of children. Children regulate their collaboration by acting on the *social motivation* to be prosocial.

Thus, to support collaboration, promote social behaviors and conflict resolution, the best course of action is to act on children's social motives to behave prosocially and activate reciprocal dynamics. According to literature, the mere exposure to actions of helping or sharing of one child to another in a game leads to (i) direct reciprocity from the child that was helped,

(ii) indirect reciprocity from other children that may have witnessed that the child was helped, (iii) more tendency to be prosocial in the group and towards the helper in the short and long term, (iv) thereby supporting collaboration.

Interestingly for our design scope, social motive and reciprocal dynamics are driven by the assessment of a person's actions and behaviors. Thus, interacting with an agent that shows prosocial behaviors will possibly bring out the prosocial, collaborative, and reciprocal norms, thereby supporting (or not) collaboration, promoting children's prosocial behaviors (helping and sharing), and reciprocity of the behaviors. That is, establishing the prosocial norm by exhibiting prosocial behaviors or triggering reciprocal dynamics.

This section has given us insights into establishing collaborative interaction with an agent and acting on children's social motive to collaborate in collaborative play. In the next section, we examine existing technological interventions to understand where to position our research.

2.3 RELATED WORK: TECHNOLOGY FOR CHILDREN'S COLLABORATIVE PLAY

Technology, both analog [212], digital [337] and socially interactive [27], contributes to supporting collaborative play dynamics.

This section aims to survey how designers of children's technology have designed interventions in collaborative play. We cover *related work in education* outlining pedagogy and school-based interventions and commercially available products for socio-emotional competencies learning, with a focus on collaboration. While successful, school-based interventions suffer from many limitations. Digital technology and socially interactive technology has addressed these limitations in the *child-computer interaction* (CCI), in *human-robot interaction* and *child-robot interaction* (cHRI) fields: the section critically presents and analyzes relevant literature to discern the state of the art of technology for collaborative play. The section concludes with a reflection on the outcomes of the analysis of the related work.k.

2.3.1 School Based and Playful Interventions

School Practices and Interventions

In educational settings, children's social-emotional competencies such as collaboration and prosocial behaviors are taught through school-based interventions and nurtured by educational products.

Traditionally, *school pedagogy* (i.e., the approach and practice to learning) have systematically overlooked children's socio-emotional learning: individual, competitive, top-down, passive learning was the norm [175]. With the increasing scientific evidence of the importance of learning socio-emotional competencies, especially collaboration [175], and prosocial behaviors, *school-based interventions* and educational practices for collaboration and prosocial

behaviors started to emerge. There is broad agreement among educators, policymakers, and the public that educational systems should graduate students who are proficient in core academic subjects and work well with others from diverse backgrounds in socially and emotionally skilled ways while practicing prosocial behaviors [130]. Being able to engage in collaborative interactions, like in collaborative play, has been linked to future economic prosperity for individuals and nations, providing critical qualities required to succeed in the global skills race [368, 109]. Schools are heavily investing in developing programs for children to learn about collaborative play skills, and companies are developing products to facilitate collaborative play and the acquisition of skills related to it.

Cooperative learning [175], as instructional practice, was the first successful example of the integration of socio-emotional learning in education [174]. Cooperative learning is based on social interdependence theory that posits the interconnects of actions among individuals [173]. Cooperative learning practices set the stage for a renewed focus on formal education's socio-emotional competencies: '*Unskilled group members cannot cooperate effectively. Effective cooperation is based on skilled teamwork as well as on-task work. Students, therefore, must be taught the interpersonal and small group skills needed for high-quality cooperation and be motivated to use them.*' (p.369) [175]. Although contributing to children's collaborative skills learning, cooperative learning is limited to the school setting and often teacher-directed. Play is not contemplated nor encouraged in cooperative learning, and activities are mainly focused on formal education.

Through the years, many other types of school-based interventions have been explored. For example, prosocial behavior promotion in childhood [120], or behavior prevention interventions against antisocial behaviors and conflicts [47, 176]. Among school-based interventions, *Socio-emotional learning* (SEL) is the current leading approach. SEL is an evidence-based approach to teach socio-emotional skills systematically [49]. SEL focuses on understanding emotion, regulating one's behavior, communicating in difficult situations, and resolving conflicts. SEL has been implemented in several Western academic system programs with good results on children's academic performance and social behavior at school. SEL applications, though, are mainly instructional and led by teachers. SEL activities mainly consist of workbooks, audiotapes, role-playing games. As a result, SEL has been found inadequate to translate to everyday life situations [335].

School-based interventions [112] have shown to support the development of strategies to regulate collaboration and stimulate prosocial behaviors [175] among children. While successful, school-based interventions suffer from many *limitations*.

School-based interventions are *top-down*, teacher-led interventions, and do not fully promote children's self-determination. Simultaneously, school-based intervention activities and program *do not capitalize on play*. Even when taking the form of toys or serious games, by revolving around hypothetical

*Limitations of
School-Based
Interventions*

prosocial dilemmas, collaborative hypothetical scenarios in school-based interventions resemble more school exercises than playful experiences. These exercises can often not capture the complexity of real-life situations like a play would, therefore failing to guide in real-life situations. Another issue with school-based interventions is the fact that they are *limited in time and space*: programs and activities are only offered for a short period and do not provide children with opportunities to practice with their peers outside the school environment [130] or in an unsupervised fashion. Foremost, school-based interventions often do not entail collaborative play, which naturally enables humans to regulate group dynamics (e.g., conflict, reciprocity) and stimulate prosocial behaviors (e.g., helping, sharing, cooperating).

Conversely, there are school philosophies and pedagogies that include play and collaborative play. *Montessori education* [254] is a 100-year-old method of schooling that was first used with impoverished preschool children in Rome, Italy. Montessori education focuses on nurturing children's independent learning by – amongst other things – increasing child–child collaboration through a series of playful activities to do in small groups with materials and objects. Even though not directly mentioned by Montessori herself, Montessori education builds upon the Vygotskian concept of Zone of Proximal Development [382]: children of different ages work together in a playful task advancing each other's learning and socio-emotional competencies.

Montessori education makes profuse use of so-called manipulative objects and toys, enabling children to design real-world things, objects, and physical structures or tangible materials to learn about various subjects playfully. Besides providing sensorial and accessibility features, Montessori manipulative objects capitalize on group interaction: manipulative objects offer a multi-hand interface, controllable by more than one person facilitating group and collaborative interactions. Montessori manipulative objects have (implicitly or explicitly) inspired commercial, educational products that aim to foster naturally occurring collaboration: Lego bricks [109], big blue blocks², Tangram puzzles, and many more.

A growing bulk of developmental psychology research [394] provides supporting evidence that nurturing collaborative play with manipulative objects among children at school and outside school contributes to children's socio-emotional development collaborative and prosocial skills mitigating the limitations of school interventions. Developmental [97, 73], social psychology [71, 17] and education [294, 232] research shows us how children better learn social skills *by doing* activities while playing with other peers, by experiencing interactions, actions and effects thereof rather than from instruction, reinforcement or scaffolding. However, only relying on collaborative play activities with manipulative objects without guidance or support

² <https://shop.imaginationplayground.com/collections/big-blocks>

leaves open questions about dealing with children who have difficulties in regulating their behavior solely within peer interactions.

In sum, education mainly deals with children learning social competencies such as collaboration and prosocial behaviors mainly with school-based interventions (SEL or other theories) or through playful learning with manipulative objects. Whilst successful, school-based interventions have many limitations focusing mainly on instructions, scaffolding, and exercises. Conversely, Montessori pedagogy and playful learning research support (with evidence) collaborative play activities with objects as a developmentally appropriate locus of socio-emotional learning. Open questions remain: Playing together in groups does not mean children will automatically cooperate, help each other, share resources or avoid conflicts. While able to collaborate and be prosocial at a behavioral and cognitive level, children might encounter difficulties that need to be tackled at a social level.

2.3.2 Computer Interventions for Collaborative Play

Researchers in *child-computer interaction* (CCI) draw on evidence-based school interventions or playful pedagogy to deliver technological interventions or products for collaborative play [335]. Typically, CCI have given predominant attention to computer-supported-cooperative-learning (CSCL) systems, rather than systems that support collaborative play and social competences thereof. *Digital and interactive technology* have the advantage to offer interactive applications for children's collaboration and collaborative play beyond the school environment [315, 335]. Interventions for children's collaboration, prosocial behaviors and collaborative play in CCI vary: from conversational agents [301] to computer games [166, 282] from multi-touch tables to tangibles [139, 296, 12, 419].

Conversational Agents

Virtual agents are computer-generated, animated characters, usually with distinctive human-like features able to interact mainly via voice and body movement engaging in conversations [301]. Virtual conversational agents have mainly been used in collaborative play to leverage the positive effects of collaborative interaction on formal learning (for example, for literacy or storytelling skills) [50]. Conversational agents are designed as *virtual peers* (either less or more experienced) or tutors with whom to engage in collaborative activities. An example of a virtual peer is SAM [50], one of the first embodied conversational playmates that, through collaborative play, supports collaborative storytelling (and indirectly literacy). Virtual agents are often embedded in various multi-modal learning environments like ECHOES [108], an environment with a rich multi-modal world in which children train social interaction collaboration skills to improve those skills. For example, FearNot is a virtual simulation with various bullying episodes where a child can take an active role in the story by advising the victim on possible coping strategies to handle the bullying situation. An extensive

Multi-touch tables evaluation of this software in schools showed promising results on using such tools in promoting prosocial behavior at school.

While the interaction with virtual agents is limited to one-child one interface interaction, *multi-touch tables* and tablets afford multi-party interaction [12]. Children play games or work on digital learning tasks through multi-touch systems. With their combination of language and actions, multi-touch systems have been found to support equitable participation and support collaboration by forcing turn-taking, and group awareness [106]. Action especially is the main way children appear to regulate collaboration around multi-touch tabletops, very much like playing with objects. While having a great effect on collaborative play dynamics, multi-touch systems are scarcely available for schools and rarely for personal use.

Computer Games Conversely, *computer games and applications* are readily available to children. Applications range from multiplayer games in which children are playing from various locations or cooperative activities around a single, shared display. Pedagogical interventions vary. Computer games mainly replicate existing school-based interventions or focus on cooperative learning. A few, like SIDES [282], revolve around promoting collaboration and skills thereof through collaborative play for children in therapy encouraging the meaningful application of group work skills such as negotiation, turn-taking, active listening, and perspective-taking. Recently, games have been exploring how to bridge the home-school barrier in the context of existing SEL interventions [335, 336]. Although supporting many aspects of collaboration and prosocial behaviors, games lack tangible dimensions proven to enhance learning (both formal and socio-emotional) through play. *Tangibles* – very much like Montessori manipulative objects – offer the possibility of co-located playful interaction that is so important for collaborative play along with interactivity of the object [12, 419]. Tangibles are computationally enhanced interactive objects, like interactive blocks or jigsaw puzzles, which have been found to encourage engagement, excitement and collaboration [285] in certain instances more than computer interfaces [12]. Amongst CCI interventions, tangibles are the ones that offer the most natural collaborative styles to the children in respect to interfaces like games and multi-touch tables [12].

Limitations

In conclusion, CCI technologies often require children to *change and adapt their collaborative style* to the technology constraint with negative consequences on children's collaboration and prosocial behavior. [245, 157]. Despite their positive effect on learning, virtual agents and games do not offer real-life collaboration with human peers. Multi-touch tabletops appear to decrease prosocial behaviors because it is hard for children to control actions and resources in collaborative play [245]. Tangibles are the interventions that most resemble traditional collaborative play, and that appear to have the most benefit on collaboration [12].

2.3.3 *Child-Robot Interventions for Collaborative Play*

A steadily growing body of Human-Robot Interaction (HRI) research shows that social robots hold promises to support children's collaboration, prosocial behaviors and resolution of conflicts [27].

*Social Robot and
Collaboration*

General HRI has found that interacting with *social robots shapes people's collaborative dynamics*: how people behave and interact with others, people's roles and the group norms [149, 187]. For example, Jung et al. [186, 187] found that *robots help teams to regulate conflicts and resource distribution*. Oliviera et al. [6], showed that the amount of prosocial behavior a group of people exhibited while playing a game was dependent on the robot's displayed goal orientation as friend or foe. Fraune and colleagues demonstrated that people favor robots that are part of the same collaborative group to humans in another collaborative group [110].

*Social Robot
Interventions for
Collaborative Play*

Recent research has started to explore social robots as an application to support children's collaborative play and dynamics thereof. Beran and colleagues [28] were the first to observe that children are keen to help a robot after the robot is presented positively by adults and suggests that children might enjoy the prosocial give take with a robot, thereby laying the groundwork for robots for collaborative play.

Social robots are mainly used as *social mediator*, a variation of a *tutoring* interaction paradigm, to promote collaborative play or conflict resolution. A robot social mediator does not engage in collaborative play and its dynamics, but it encourages collaboration, prosocial behavior, and conflict resolution with various verbal strategies. The IROMEC project [164] provided early indication about how robotic toys can become social mediators, encouraging children with special needs to discover a range of play styles, from solitary to collaborative play. Results from a study with KASPAR [383], a humanoid robot design for non-typically developing robots on the autism spectrum, found that playing a collaborative game with Kaspar led to more collaborative behaviors than with a human. Sebo and Scasellati showed that a conversational robot that uses task and relational, verbal strategies of promoting collaboration impacts collaboration outcomes among children [354]. Shen, Slovak, and Jung [324] demonstrated that a robot taking the role of mediator and using evidence-based verbal strategies (taken from SEL school-based interventions) of conflict helps young children to resolve interpersonal conflict about sharing resources in playful activities.

*Opportunities,
Limitations, Open
Questions*

All in all, social robots appear promising in supporting children's collaborative play. By leveraging the ability to establish social interaction through social presence, robots combine the benefits of school-based intervention (by taking mediating roles), playful pedagogy (by affording playful interaction), and computer interventions (by affording flow and tangible interactions).

Although the status quo in cHRI, tutoring robot interventions might suffer from the same limitations of school-based interventions. By replicating formats and activities usual in formal education, interaction with tutoring

robots in collaborative play might not be able to be translated to real-life situations. Even teachers question the role tutor robots should take in children’s activities [318]. Playful paradigms might be more suited to embody playful pedagogy.

2.3.4 *Related work: Conclusions*

In this section, we have outlined the technological interventions on children’s collaborative play from multiple perspectives.

We have learned that schools intervene to nurture children’s collaborative skills through tutoring and evidence-based educational programs [130]. These programs revolve around hypothetical collaborative scenarios and teaching children strategies to apply in those scenarios [111]. The main drawback is that children’s strategies are hardly applicable in real-life scenarios, which are more complex and multifaceted than hypothetical scenarios. Real-life practice through play with peers is the best way for children to master collaboration [97, 281, 300]. However, play-based opportunities for training collaborative skills and nurture prosocial behaviors are less and less available to children [109], especially in elementary school. Therefore, the impact of school interventions often remains at a surface level. Many of the proposed technological interventions to nurture collaboration suffer from similar limitations. Social robots that promote collaboration have applied tutoring approaches with mixed success [354, 324].

From the analysis of the various available interventions, it follows that social robots are uniquely positioned as an intervention for a (Montessori-inspired) playful pedagogy. Albeit they have shown positive results for children’s learning, tutoring robots shared too many limitations with school-based interventions and virtual agents. A shift towards social robotics playful paradigms to support children’s collaboration might favor the natural way children learn to collaborate. In the next section, we examine how we could design social robot’s communication to intervene in collaborative play.

2.4 DESIGNING SOCIAL ROBOT COMMUNICATION

A robot needs to communicate its states, goals, and intentions to interact with children [67]. Especially in collaborative play, whereas we have learned – the communication of social motivation to collaborate has a potent effect on collaborative dynamics.

In the previous sections, we have seen that the communication between children and robots comes from the interplay of a robot’s appearance and behaviors. Irrespective of the form or the behavior a social robot has or exhibits, the role of children’s expectations, interpretations, and understanding is vital. Designing for an appropriate interpretation of the robot’s behavior is thus one of the challenges of cHRI researchers.

In this section, we hone-in on how to design social robot communication to achieve cHRI effectively. One of the prerequisites for a social robot to interact with children and affect children's collaborative play is communicating with them. The goal of our analysis of related work and theory is to discern how we could design robots to maximize a responsible illusion of life: communicating vividly to children without deceiving them and raising unattainable expectations. The section is organized as follows: First, we critically analyze what we defined as the two ways of designing social robot communication: designing for human-like communication and designing to communicate in 'human terms'. We describe in detail the theories that substantiate both practices. Second, we detail the methods to design social robot communication. Then, we conclude the section with a reflection on designing social robot communication for children.

2.4.1 *Designing for Human-like Communication*

As we have seen in this chapter, HRI and cHRI have usually replicated human appearance (the form of a robot), human modalities (the ways to communicate, for example, voice or gestures), and human behaviors to achieve human-robot communication and ease human-robot interaction [67]. In HRI, most of the robots are designed to look like and communicate as much as possible like a human would do, especially using natural language. To understand a human-like looking and behaving robot, a human would use prior knowledge about conventional, codified human communication (e.g., natural language or conventional gestures) and apply it to interact with robots. Robots' behaviors are actively designed to communicate with humans socially in various ways.

*Verbal and Non-Verbal
Interaction*

Social robot communication has been designed predominantly to communicate in '*human-like ways*'. Human-like communication can be both verbal and nonverbal. According to some scholars [55] verbal interaction is innate in humans; according to others, it is codified evolution of nonverbal behaviors motivated by the need to collaborate for evolutionary advantage [361]. Verbal interaction is neither innate nor evolved in social robots but is carefully designed to be as natural as possible [18]. Verbal communication consists of utterances, units of speech that humans use to establish communication, share information, and emotional states with each other [361]. Utterances consist of words, vocalizations, and fillers. Designing verbal communication in human-like ways means dealing with natural language generation, dialogue management, speech, and language recognition. Utterances are modeled on natural language and conversational norms [27, 18]. Nonverbal communication in human-like communication is used to punctuate verbal communication of extra social information [258]. Nonverbal communication could serve social robots for human-like emotions, moods, stances, or support human-robot engagement, both in terms of attention [257] and interest. Nonverbal communication channels mimic the ones

of humans [13]. Hence, gaze and eye movement, gestures, posture, and bodily movements are replicated with varying degrees of success [18]. Facial expressions are also replicated from human expressions to communicate emotions and affect. Nonverbal communication is technically generated through various techniques like animation or cognitive architectures, but it is conceptualized from observations of human behavior [258], derived from human-human interaction theory [39] or from robot learning.

*Human-Like
Communication
Modalities*

Research posits that to communicate with humans socially, a robot should leverage communication modalities that humans have [67] (e.g., speech, natural language, facial expressions, human-like gaze, hand gestures, human-like head movements, human locomotion). A robot should behave as humans do (e.g., flowing conversations, back-channeling speech, coherent expressions of emotions, appropriate approaches, articulate gestures). The primary assumption in social robotics is that robots should adhere as much as possible to the modalities and norms of humans communication [39, 20]. If a robot communicates in human-like ways, humans apply existing mental models and social norms to understand the robot's communication, interacting with the robot as they would do with another human [18]. Much of the HRI and cHRI literature focuses on designing to communicate in human-like ways. However, as we have covered in previous sections, it brings notable limitations to HRI in general and to cHRI in particular.

2.4.2 *Designing Communication in Human Terms*

An alternative approach to human-like robot communication is to communicate in 'human terms'. We coin the term to describe researchers and designers' work who leveraged humans' tendency to make sense and attribute intention to objects that move and behave in an animate, agentic, and contingent way to design robot communication with humans.

Communicating in human-terms as a concept is grounded in developmental psychology, social psychology, and HRI. Humans are sensitive to motion, and they make sense of it in human terms. This phenomenon does not only have to do with the tendency to ascribe anthropomorphism to robots and other entities. However, it has to do with the human tendency to extract information from visual features and parse them intentionally if certain conditions are met. Heider and Simmel [142] showed in a seminal study that people ascribe narratives, human emotions, and intentions to abstract geometric figures that move in ways that suggest intentions. In other words, Heider and Simmel gave empirical proof of the fact that people tend to anthropomorphize the motion of any entity that appears to move intentionally. Humans make sense of it as if it was a human while maintaining that – in fact – the entity they are observing is not human at all. The phenomenon unveiled by Heider and Simmel and extended by Johnson [178] rests on our cognitive infrastructure to understand and share intentions to communicate and how humans explain behaviors they experience.

*Non-conventional,
Non-verbal, Action
Based Communication*

Tomasello [361] (building on Grice [131]) posits that human communicative acts rest on the ability to share a social intention. Hence, an intention-sharing infrastructure is hardwired in human cognition, making sense of what others want to communicate regardless of the communicative act. Sharing intention can be done via verbal and nonverbal communication. However, the intention-sharing infrastructure, the basic psychological infrastructure of human communication, originated from nonverbal communication. Tomasello explains that while language is culturally built and culturally specific nonverbal communication is universally understood by humans. The hardwired ability to understand each other's intentions developed from our primordial needs to understand other humans or other entities from nonverbal behavior to guarantee survival. Humans needed to understand each other's nonverbal behavior, particularly each other's actions, to cooperate for evolutionary advantages such as, for instance, hunting together. Tomasello identifies the pillars of non-conventional, non-verbal, action-based communication to share intentions. The communication should take place in the joint attentional space to be perceived; this joint attentional space needs to be clear to the two or more communicators. Actions should clarify who is the recipient of the communication (whom a communicator is addressing) and the object of the communication (what the communicator is referring to). The action itself should embody the goal of communication. For example, extending the hand toward a person indicates the willingness to give something.

*Folk-Conceptual Theory
of Action*

Malle [240] explains in his Folk-Conceptual Theory of Action Explanation that any behaviors that we perceive visually, such as actions or movements that are goal-directed and have animacy (like the objects in Heider's study), will look like and be parsed as intentional by humans. The reason for this is directly connected with Tomasello's theory. Malle explains that *"Throughout development, humans learn a large number of 'prototypes' of intentional action, and language codifies many of these prototypes in action verbs that imply intentionality (e.g., reach, walk, look, help)"* [240, p. 307]. Therefore, when humans see or perceive movement that reminds them of such inherent prototypes of intentional actions, they will interpret it as intentional. Malle continues explaining that humans interpret and explain agents' actions by providing reasons for their behaviors. Humans assume that the behavior is intentional and try to identify the agent's possible mental states based on which the agent has acted. Communication in 'human terms' rests on humans' hardwired ability to perceive and interpret motion in social terms and ultimately explain it.

The HRI scholarly work has so far unveiled several dynamics of the communication in 'human terms', but there are still crucial challenges to address. First, by focusing on designing robots to communicate in 'human terms', designers do not need a human-like form or human-like modalities to establish HRI. This body of work is generally concerned with endowing low to non-anthropomorphic robots with expressive behaviors [153] to achieve

effective communications with humans. Previous work in this direction focused on understanding how specific features of animation might support communication [356], trying to translate psychological traits in robot motion through bodily improvisations [344] or uncovering the expressive power of a robot's functional motion exploring frameworks from acting and theater practices [204]. The primary communication channel is nonverbal, focusing on kinesics.

However, when designing robot communication, it is hard to anticipate how people interpret a robot's motion or nonverbal behavior [207]. A comprehensive theory of the interpretation of the motion of an agent under various interactive circumstances is missing. Furthermore, the design implications from the HRI literature might not generalize for every low/non-anthropomorphic robot. The variability of interpretation is already high when a robot communicates in human-like ways [183]. Therefore it is arduous to design a robot behavior that effectively communicates in 'human-terms'. Previous work [151] has referenced the psychological infrastructure that allows communicating in human terms, but (to the best of our knowledge) a break-down of the behaviors needed to achieve communication in human-terms is missing, along with a clear set of guidelines on how to design behaviors that communicate in 'human terms'.

2.4.3 *Designing Social Robot Communication Approaches*

A robot communicates by leveraging the interplay of surface appearance and physical motion, sound, and illumination modalities [258]. Movements [151], sounds (both verbal [195], and nonverbal [409]), and lights in isolation or together constitute the way a robot behaves to communicate. How are robots' behaviors designed to communicate with humans socially?

HRI and cHRI stem from engineering and social science practices [18]. The HRI design process is linked to technical investigations to advance robotics technology or understand how people experience robots [18]. Initially, HRI design processes focused on technology optimization rather than user experience and interaction design. With the prospect of robots entering society, design questions and implementations stemmed from an interest in understanding how people experience robots, thus from disciplines such as psychology. In this perspective, robots are designed, taking into account psychological theories or observing human behavior. Design methodologies from HCI and design research are becoming more and more usual in the design of robots. User-centered design (used, for instance, by Lee et al. [219]) an approach focused on designing for the user(s), is the most popular design method. Co-design (explored by Lee and Šabanović [220] and Alves-Oliveira et al. [7]), which is focused on empowering users to participate and have a say in the design process is getting attention. Research-through-design (advocated by Luria et al., [236]), which is focused on carrying out explorations to understand "*what is the right thing to design*" [236] (page 3) is

starting to get traction. As a result, we are witnessing a shift towards multi and interdisciplinary approaches. Many advocate diverse design teams, but – in comparison with HCI– established and validated design methods and processes are lacking, mainly to design both the form and the robot behaviors.

Nevertheless, it is possible to distinguish three approaches to designing the form and communication of social robots as summarized by [151]). Mechatronic methods stem from the engineering and robotics field. The main focus of mechatronic methods is on the interplay between the robot form with its function. In mechatronics, the form of a robot is usually subordinated to the goals of the engineering research [167], with less focus on user experience. Mechatronics methods strive to optimize sensing and mechanics in a form that makes sense with the engineering goals. From functional purposes (e.g., optimizing motion paths or a cost-function) to the one-on-one replication of biological forms (either human or animal) for scientific research (e.g., cognitive science) [237]. Industrial design approaches follow design-research methods conventional in the realm of product development. Social robots are considered from a design-centered perspective as products that facilitate the experience and interaction [20] They encompass various processes from understanding context and users to ideation and evaluation. Industrial design-oriented approaches use several methods and techniques such as sketching, prototyping, morphological charts, and user research [20, 80, 81, 191, 222, 235]. Industrial design approaches stem from design-research and are focused on the interplay of aesthetics, social function, and user experience. They are geared to the design of social or entertainment robots, thus robots that have communication with humans at its core, with particular attention for communication norms. Industrial design approaches usually start with exploring the appearance of the robot and then focuses on behavior design. Behaviors are designed starting from theory, from observation, or optimization of form and function.

Mechatronics, Industrial design, and movement centered approaches

The last approach is a movement-centered approach. The movement-centered approach is geared to surface the people's tacit knowledge about a robot's behavior and use this knowledge to design robots carefully. The form of the robot is somewhat subordinated to the motion design, leading to "*mechanically and formally simple robots that display sophistication in the way they move instead of in the way they look*" p. 95 [151], like everyday-objects robots (e.g., doors, ottomans, microphones) [181, 333, 359], or abstract robots [150, 154]. Designing with movement in mind (as defined by Hoffman and Ju [151]) is a process that factors in mechanics, expressiveness, aesthetics, and user experience through iterative design explorations. Behaviors are designed contingent on the form. The inspiration for behavior design comes from the exploration of movements and animation principles. Generally, this approach is geared towards designing robots communicating in human-terms rather than human-like.

No matter the approach, designing a robot's communication is effortful, and there is no consensus regarding best practices and design processes

2.4.4 *Designing Social Robot Communication: Conclusions*

In this section, we introduced and discussed how to design social robot communication. We systematized the HRI literature on the matter in a dichotomy: designing for human-like communication and designing in human-terms, terms we coined to describe the main strands of communication design in HRI.

Designing social robots to communicate in human-like ways means leveraging the channels, modalities, norms, and codes of human communication. When designers design human-like communication, they leverage human-like affordances of the robot's appearance and behaviors. Conversely, designing social robots to communicate in 'human terms' means leveraging the human cognitive infrastructure hardwired to make sense of intentions. Designing in human-terms rests on humans' tendency to parse movements and nonverbal sounds of — even abstract — entities and attribute intentions to it, respond to it, and ultimately recognize it as an agent. When designers design social robots to communicate in 'human terms', they explore the design space of nonverbal behaviors and their interplay with surface appearance. Typically, designers make use of less human-like features to communicate.

We summarized the three predominant design approaches in HRI: mechatronics, Industrial design, and movement-centered approaches. While all the approaches are applicable to designing a robot's communication in a human-like and 'human term fashion', the movement-centered approach is geared towards designing robot communication in human-terms.

To the best of our knowledge, there is no consensus regarding best practices and design processes. While research has shown how potent the communication in '*human-terms*' can be, coherent and comprehensive design guidelines are missing. The child-robot interaction literature is particularly scarce on the matter. Little is known about the essential elements required to communicate in 'human-terms' or communicate a robot's intention effectively solely with non-anthropomorphic and nonverbal communication. An urgent question concerns how to design behaviors and interactions under the premises of communication in 'human terms'. Overall, the explorations of robot communication demand a deeper understanding of communication mechanisms in 'human terms', especially when designing for children.

2.5 CONCEPTUAL FRAMEWORK

In this chapter, we have critically examined literature from various disciplines to understand better how to design to support children's collaboration

in play and promote prosocial behavior. However, the chapter’s goal is to present the theoretical background of the dissertation and elaborate the knowledge gained through the perusal of the literature in a conceptual framework. Hence, in this section, we summarize what we have learned in the perusal of theory and related work by developing a conceptual framework to guide our research.

We explain the child-robot intervention and child-robot communication we envision, along with the design principles to make our vision actionable. Lastly, we define the type of robots we will research.

2.5.1 *Intervening in Collaboration Between Children: Exploring Playful Interventions*

Drawing from the literature we examined, we consider the phenomenon of play a multi-dimensional array of activities to master several socio-emotional competencies while experiencing joy. We consider playing not as a meaningless children’s activity but as the primary locus of children’s development.

Following the Vygotskian tradition, [382], we consider collaborative play as a locus of socio-emotional learning for a small group of children: during collaborative play, children learn through experience by interacting with peers and adults. In particular, children learn how to regulate collaboration, prosocial behaviors and resolve conflict. Therefore, we consider it fundamental to establish collaborative interactions among peers (or children and adults) to support children in learning how to regulate collaboration.

The main reason to intervene to support collaboration and promote prosocial behaviors in collaborative play is that playing together in groups does not mean children will automatically co-operate, help each other, share resources and avoid conflicts [31]. While able to collaborate and be prosocial at a behavioral and cognitive level, at a social level, children might encounter difficulties, which can have relevant consequences on their *socio-emotional development* and skills thereof [260]. Thus, we explore a playful intervention to support children’s collaboration in play with social robotic technology. At the *intervention level*, our goal is to promote the social level of collaboration, trying to act on children’s motivation to be prosocial to one another in collaborative play. The robot aims to influence children to collaborate and be prosocial through participating in play: by showing prosocial behaviors, the robot tries to influence children’s behaviors. When we interact with somebody that helps us, we are compelled to help in return [264]. When we work in a team, we tend to collaborate more with each other when teammates share resources and information with us [249]. Children experience a similar effect when playing together [284]. Research shows that mere exposure to the action of helping or sharing of one child in play leads to reciprocity and a greater tendency to be prosocial in the short and long term [101]. Actions such as helping, sharing, and informing establish the prosocial norm

Playful Intervention

Figure 8: The diagram is summarizing our conceptual framework.

and prompt reciprocal dynamics in a group [96]. Prosocial and reciprocal dynamics promote collaboration, even when collaboration is challenging [248].

Figure 8 visualized the intervention we will explore in the dissertation.

Figure 8 visualized the intervention we are going to explore in the dissertation.

2.5.2 Beyond the Social Robot Status Quo: Communicating in Human Terms

This dissertation positions itself in the body of child-robot interaction research that is challenging the status quo of tutoring robots. We motivate this choice in two ways: (i) we believe that playful interaction paradigms might enable interaction with ethical and developmental concerns, and (ii) by revolving around playful interaction, we believe that playful robots are uniquely positioned to embody our envisioned intervention.

By focusing on low- to non-anthropomorphic social robots for children, we opt to design child-robot communication in human-terms. To this end, at the *communication level*, the robot needs to communicate in human-terms its intention to be prosocial to the children. To clarify what communicating in human-terms in our setting means, let us consider the following example:

Let us think about a ball (see also Figure 9). There is a ball which suddenly starts to move towards us, without being pushed by anybody. The ball directs itself towards us, rolls towards us, and pushes a box with it while rolling. Then, the ball stops in front of us. Why is the ball doing this? We can infer the ball's intention from its actions: It looks like the ball wants us to have the box. The way we infer the ball's intention from its action is a simple example of communicating in 'human terms'. Thus, communicating

Figure 9: The figure is exemplifying what it means to communicate in ‘human terms’. A ball suddenly starts to move autonomously towards a person without being pushed by anybody. The ball directs itself towards the person, rolls towards the person, and pushes a box with it while rolling. Then, the ball stops in front of the person. Why is the ball doing this? We can infer the ball’s intention from its actions: It looks like the ball wants us to have the box.

in ‘*human terms*’ means designing a robot’s behavior in such a way that it leverages the tendency of humans to parse movements and nonverbal sounds of — even abstract — objects and attribute intentions to it, respond to it, and ultimately recognize it as an agent.

While communicating in ‘human terms’ relieves from the need for a human-like form or human-like modalities, it brings the challenge of designing behavior that readily communicates, legible, and explainable by children, factoring in their tendency to play with the illusion of life. To guide our design explorations, we then translate Tomasello and Malle’s theories to design principles to guide the design of the robot communication. To summarize, the principles are (i) *Shared Space*: to communicate its intention a low/non-anthropomorphic robot should interact in a shared space in front of the children; (ii) *Grounding Communication*: The space, the people, and the objects in the space should be clear, the robot should not refer to people, objects or spaces that are not in the shared space; (iii) *Grounding Subject* A low/non-anthropomorphic robot should clarify the recipient of its communication by aiming at the recipient with the movement it affords; (iv) *Grounding Objects*: a low/non-anthropomorphic robot should clarify the object of its communication aiming at the object with the movement it affords; (v) *Action=social communication*: The actions of a low/non-anthropomorphic robot should embody the goal of the communication, with no need for a motion-style; (vi) *Primary actions* a low/non-anthropomorphic robot should use actions such as giving, walking, pointing, and nudging because the intention of these actions is obvious to humans: they are sort of primary actions that encapsulate intentionality; and (vii) *Legibility*: an interactant should be able to explain the reason of a low/non-anthropomorphic robot behavior only by experiencing/watching the behavior.

Design Principles

Hence, the communication level is as follows (See Figure 8): A robot needs to act in the shared communication space with the children. The robot needs to clarify whom it is addressing and what it is addressing. Its actions

Figure 10: The Figure is visualizing our design principles.

to participate in play with children should readily embody the robot's prosocial intention to communicate to promote collaboration. The robot uses actions that are stereotypes of prosocial communication (like giving and pointing) or other actions that are contingent on the playful setting and evident to humans (like "walking"). The behavior of the robot should be designed to be legible by children by only experiencing the interaction.

2.5.3 *Robothings*

In this chapter, we have honed-in on the scope of our research. The research explores how robotic technology that looks similar to the objects children play with and does not have a set of human-like modalities could promote collaboration among children. This dissertation probes the design space of non-anthropomorphic nonverbal social communication for robots. We will refer to these robots as *robothings*. The term *robothing* derives from the term robot and the term thing. As simple as it sounds, the term encapsulates the considerations we have made regarding cHRI paradigms. The prefix 'robo' is an abbreviation of the word robot. It indicates an autonomous artificial agent that is embodied and communicates. The suffix thing is related to the word 'thing,' but it connects with the concept of things developed by the philosopher Bruno Latour [215]. For Latour, everyday objects are not inanimate, nor are simple tools. Objects shape the way we perform actions (e.g., a crutch changes the way we move in space, augment our possibilities for action, and shapes our demeanor); they extend our capabilities (e.g., the microscope is a physical augmentation and extension of our visual capabilities, changing the way we make sense of the world our us), shaping the way we make sense of and perceive ourselves and the world.

Things as mediators

This concept has been further extended in the Theory of Technological mediation [374]: Rather than approaching technologies as material, inanimate objects or as mere extensions of human beings, it sees them as mediators of human-world relations, supporting and influencing how people act and make sense of the world. In this dissertation, we consider things from a technological mediation perspective: things affect people's agency inherently and shape our practices. Thus, conceptually robothings refer to things as robotic objects mediators of the children-world relationship.

Concretely, robothings are hybrids between objects and social robots. Robothings are low/non-anthropomorphic robots that communicate their prosocial intentions to influence people's behaviors, leveraging their nonverbal communication affordances. We conceptualize the role of a robothing as an interactive "*thing*", with its own agency, rather than a human-like partner (e.g., teacher, friend, etcetera) that aims at a human-like agency. We consider robothings as social robotic technology focusing on a playful interaction paradigm. The interaction with robothings aims to bring a specific set of *values* to the interaction with children: (i) *Children's independent reflection in action*: by intervening in play *by playing* with prosocial actions in the game, the robothing enable children's thinking about prosocial behaviors. A robothing should not indicate to the children what actions are right to take but should stimulate reciprocity or other prosocial dynamics to enable children's reflection-in-action in collaborative play; (ii) *Children's agency over the robot's agency*: in the interaction with robothings, children are the primary agents, ultimately in charge of the interaction. While a robothing aims to influence children's behavior, robothings do not have a normative function. It is a vehicle of playful reflection; it does not have control over children's behavior.

Values

This dissertation explores what it means for a robothing to communicate in 'human terms' to children. By leveraging nonverbal communication in 'human terms', a robothing could mitigate the adverse effects humanoid robots might have by relying only on low/non-anthropomorphic cues and behaviors. Overall, the explorations of a robothing communication demand a deeper understanding of communication mechanisms in 'human terms', especially when designing for children.

2.6 CHAPTER CONCLUSIONS

This chapter has critically examined literature in cHRI, HRI, developmental psychology, HCI, CCI, and child psychology to develop a conceptual framework. The conceptual framework helps us define what are robothings and offer a compass to the research.

The literature's perusal was challenging and surfaced the many facets and challenges of designing robotic technology for children. It helped us to define our position from multiple points of view. First, we position our work with the research strand that is challenging the status quo of social

robots. We focus on playful interaction paradigms and playful interventions in children’s collaborative play.

We inform RQ1. *How do children regulate prosocial behaviors to collaborate in play?* by examining and breaking down the phenomenon of children’s collaboration. We learn that the social level of collaboration impacts social dynamics like prosocial behaviors and conflict resolution, and task dynamics. Hence, children regulate their collaboration by acting on the social motivation to be prosocial. This knowledge grounds our intervention in collaborative play.

Intervention-wise, we focused on co-located playful interaction similar to natural child-child interaction with robotic agents rather than instruction-like interactions. A robothing should show prosocial behaviors and prosocial strategies to promote children’s collaboration and prosocial behaviors. Thereby, we inform RQ2. *How should the interaction with a robothing be designed to impact prosocial dynamics in play?*

Our research focuses on design technology that can communicate goals, intentions, and social motives, as it is a prerequisite to collaborative engagement and prosocial behaviors. Instead of designing robothings to communicate in human-like ways, we focus on achieving communication in ‘human terms’. The latter leverages the tendency of humans to attribute states, goals, intentions, emotions, and social traits to virtually anything that moves in a contingent way in the space [240]. Thanks to this human propensity, low/non-anthropomorphic robots’ motion and nonverbal behaviors alone cue what actions and interactions are possible. As a result, communication in ‘human terms’ relieves robots from the need for a human-like form or human-like modalities.

To tackle the challenge of designing a robothing to communicate in ‘human terms’, we delved into the theories of human communication and behavior understanding. Based on these theories, we define seven actionable principles to guide the design of a robothing’s behavior, thereby informing RQ3 *How should the nonverbal behavior of low/non-anthropomorphic robots be designed to communicate a robot’s intention to children?*

BEHAVIORAL OBSERVATION STUDY OF CHILDREN'S COLLABORATIVE PLAY AND SCENARIOS

"Apes, like chimps, do not point at each other, only humans do so in order to attract attention, that is, to (get) help, play and share experiences."

Michael Tommasello (2008) ^a

^a I suggest to listen to the song **Scientists** by Four Tet while reading this chapter

Chapter 3 presents a behavioral observation study. In this study, we observed children engaged in collaborative play. We sought to understand what prosocial and conflict dynamics children exhibit, the role of prosocial and conflict behaviors in regulating collaborating play, what group dynamics emerge, and how the type of task impacts children's behaviors and dynamics. This knowledge helped us identify design opportunities. We show that children find it hard to regulate the social dynamics of collaborative play. Children resort to conflict more than they show prosocial behavior. Children tend to play in sub-groups instead of playing with all the group members. The group dynamics show that children tend to dominate or exclude other children from collaborative play dynamics. We also observed that the type of collaborative play task plays a role in enabling more or less collaboration. In particular, collaborative games with rules support the emergence of collaborative dynamics, while in open-ended tasks, children play less together. The findings of the observation study inform our scenario design.

Chapter 3 is largely based on: V. Charisi, C. Zaga, and V.Evers D1.2 Report on User Behavior (Squirrel (Clearing Clutter Bit by Bit) Project, Public Deliverable, Technical Report University of Twente, (January 2015)

Part of the results presented in this chapter have been included in the following publication: Kim, J. Truong, K. P., Charisi, V. , Zaga, C., Lohse, M. , Heylen, D. and Evers, V. (2015): "Vocal turn-taking patterns in groups of children performing collaborative tasks: an exploratory study", In INTERSPEECH-2015, 1645-1649.

3.1 CHAPTER INTRODUCTION

Motivation

Children play on their own, but also engage in playful activities with other people. When engaged in playful activities with people, the task and social dynamics depend on what children do in the interaction. Thus, to understand how children regulate prosocial behaviors and deal with conflicts in collaborative play, we need to observe their naturally occurring behavior.

When children are involved in collaborative play their actions, attention and intentions must be coordinated. Children's behaviors in collaborative play are an expression of children's cognitive and socio-emotional processes. Children's actions coordinate intentions and movements to physically engage in a collaborative task (e.g., build a construction), but also have a social function. Children's actions in collaborative play underpin prosocial motives (e.g., helping, sharing) and group dynamics (e.g., aggression and conflict).

Literature provides indications of behaviors children exhibit and dynamics which emerge in collaborative play, but not at a level of granularity to understand how behavioral and social dynamics unfold in a single play session. Little is known about the exact behaviors children exhibit during collaboration in play. Knowing how a child acts, reacts, and regulates behaviorally prosocial behavior during collaboration in play is essential to envision the interaction scenarios as well as detailing opportunities for a robothing's intervention. It is necessary to have a granular knowledge of children's behavior in collaboration to design the intervention of a robothing.

Therefore, we decided to observe how children behave in collaborative play, focusing primarily on non-verbal behavior. In design-research [216] and Computer-Supported Collaborative Work (CSCW) [121, 338] it is common to complement literature reviews about human-interaction phenomena with observations of people in context, prior to design exploration. Insights from observations fuel the design process with more ecologically valid and high-fidelity insights of the phenomenon under consideration.

Observational Study Overview

In this chapter, we present an **observational study** of small groups of children (n triads = 7, 9 female and 12 male, $n = 21$) aged 5 to 8 ($M = 6.95$, $SD = .95$) engaged in collaborative play and we introduce the interaction scenarios developed on the basis of the observations' findings.

Through systematic inductive and sequential coding [16] of children's nonverbal behaviors, we discern the prosocial, conflict and group dynamics emerging in small-group collaborative play and we shed light on how a different playful task influences children's collaborative behaviors. We illustrate the design implications of our findings and detail interaction scenarios designed bearing in mind what we have learned from our observation study. The chapter contributes to our first research question, namely:

- RQ1. *How do children regulate prosocial behaviors to collaborate in play?*

The chapter concludes discussing how we inform this research question.

3.2 STUDY 1: BEHAVIORAL OBSERVATION OF CHILDREN COLLABORATIVE PLAY

3.2.1 *Related Work and Research Questions*

Developmental psychologists have used observations to understand the social world of a child since the 1920s and 1930s. One of the first examples of systematic observations of children's behaviors is Parten's study [277] (see Chapter 2) of social behaviors during play. Parten observed children's behavior for 1 minute a day of indoor free play for a school year. From the observations, Parten elaborated on many categories of children's social play.

After Parten, many scholars [341, 15, 280] started to systematically observe children's behaviors, developing coding schemes and methods to carry out observations. Systematic observation is a way to quantify occurring behaviors and differs from narrative approaches that aim to qualify children's behaviors [16].

Typically, coding schemes are either "*physical*" coding schemes of low-level overt physical behaviors of children or "*social*" coding schemes, labeling interactions, and dynamics [16]. Annotations are made either of *occurrences of behaviors* (i.e., counts and frequency) or sequences of behaviors, that take into account how behaviors unfold (i.e., what happened before or after a certain behavior) [16]. Both verbal [127] and nonverbal behavior [341] is considered in children's observations.

What we know about children's behavior in collaborative play

The literature has shown some of the behaviors children exhibit in collaborative play. Scholars indicate that object possession struggle and physical struggle during play are types of overt actions found to signal aggression and conflict among children [248, 16]. Conversely, giving objects to another is considered an act of sharing, and picking up an item for another person is deemed to be instrumental help-giving—both prosocial behaviors [91]. Pointing has been found as a critical referential gesture to redirect attention in collaborative play to coordinate behaviors and provide help [46].

Conversations (e.g., agreement, disagreements, arguments) are used by children to regulate collaboration [127]. In middle childhood, though, children talk to each other to organize collaborative learning tasks rather than playful tasks. Despite the numerous studies on the matter, literature does not provide a clear overview of children's behaviors during collaborative interactions, especially little is known about the nonverbal physical actions children display. Also, little is known about the sequential dynamics of these actions regarding how children respond to prosocial or conflict behaviors in collaborative play.

We know from literature (See Chapter 2) that children, when collaborating effectively, tend to respond prosocially to prosocial behaviors, like helping or sharing, and to reciprocate those behaviors. Conversely, chil-

dren tend to ignore or respond aggressively to prosocial behavior when the collaboration is not optimized, and the group is not cohesive, thereby experiencing conflict. However, we do not know what behaviors children are actually displaying. Such knowledge is fundamental to design interventions in collaborative play. Thus, we ask:

- **Sub-question 1:** *What prosocial and conflict behavior do children display in collaborative play?*
- **Sub-question 2:** *What role does children's prosocial and conflict behavior play in regulating collaborative play?*

In terms of social behaviors, scholars have mainly focused on group dynamics: the roles children take in collaborative play and the small-group formation thereof. Stoneman [350] has shown that children take different roles when playing together: from dominant to less dominant, from knowledgeable to less knowledgeable roles. Scholars have observed that roles are influenced by whether children play together collaboratively, alone [16] or in sub-groups (e.g., Simmel effect [329]). We know that during open-ended play, children tend to shift from solitary to collaborative play depending on dynamics such as conflict and prosocial behavior [248].

Children divide into subgroups when collaborating to break tasks down, but a sub-group could also divide the group, thus creating an imbalance in the collaboration. Exclusion of a child from the activity might emerge, causing conflict and less prosocial behaviors. Sub-group formation has an impact on how children perceive themselves as part of a group: For instance, when children consider themselves as part of a group, they tend to prefer and be more prosocial among group members [205]. Considering children's group dynamics, we ask:

- **Sub-question 3.** *What is the impact of sub-group formation on group dynamics?*

The role of the Task

The CSCW and HCI literature has shown that the type of collaborative task might impact collaborative play dynamics. Go et al. [121] observed children playing various games to unveil how social dynamics between siblings influence gameplay and how social dynamics and gameplay changes depending on the type of the task. Volda et al [378] have found that the type of game influences social dynamics mainly at the group level. Contrary to the authors' expectations, when children play competitive games, children show group-oriented practices while playing a more individualistic way when playing a collaborative game. Davison et al [69] observed that children engaged in a collaborative task, like balancing a beam, the task is punctuated by many social behaviors that emerge because of the game's very structure. Given the role of a playful task on children's behaviors, we ask:

- **Subquestion 4.** *What is the impact of the type of collaborative task on children's prosocial and group dynamic?*

Overall, we have shown that observing children's behavior offers a window on how they regulate collaborative play. Knowing how a child act, reacts and regulates behaviorally prosocial behavior during collaboration in play is essential to envision the interaction scenarios and detailing opportunities to intervene in collaborative play. Related work provides insights on children's behavior in small-group collaboration. However, we lack granular knowledge. Little is known about the prosocial and conflict behavior children display and how they regulate collaborative play. The positive regulation of group dynamics is the key to successful collaborative play. Again, we do not have sufficient information about the impact of crucial group dynamics like subgroup formation on the collaborative play. Apart from social dynamics, literature shows that the type of collaborative tasks might play a role in prosocial and group dynamics.

We sought to address these gaps in the literature by conducting an observational study. In the next section, we detail the method of the study.

3.2.2 *Methods*

We carried out an analog observation [146] of children in collaborative play in the wild. Thus, we provided children with a given collaborative play task. The goal was to enable the emergence of relevant interactions for collaborative play. We set the observations outside the laboratory, in the “wild” (i.e., children’s school), to guarantee a degree of ecological validity.

We audio-video recorded seven sessions totaling 3 hours of interaction. We analyzed the video data with a systematic behavioral approach [127] focusing primarily on nonverbal behaviors, particularly on actions. We developed an inductive coding scheme to annotate behavior type, frequency, and sequence [16].

Participants

Children (n triads = 7, 9 female and 12 male, n = 21) aged 5 to 8 (m = 6.95 sd = .95) from a public Montessori school in the east of the Netherlands participated in the analogue observation study. Children were assigned randomly to a mixed-gender, mixed age group of three (triad) for each session. The unit of analysis is the triad (7 groups of three children) and the single children in the triad. All the participants experienced all three collaborative play activities.

Ethics

The ethical committee approved the observation study of the University of Twente (NL). The data collection, the protocol, and the data analysis comply with the standard ethical requirement for protected populations (i.e., children). The school headmaster and teachers gave consent for the study to occur in their facilities and during school time. Children’s legal guardians provided written permission for the children to participate in the study. Children were informed before the study’s commencement about the activities and data recording and gave verbal consent to participate. We have provided all children the choice to stop with the activity and recording anytime they wished. One child withdrew support, and as a result, we have not included data from one of the triads.

Task and Materials

Children were asked to participate in playful construction activities. We devised three different 3D construction activities with commercially available magnetic wooden blocks (Tegu block¹) to observe children’s collaborative play (Figure 11). During all the three collaborative play activities, each child had a bucket with magnetic blocks at their disposal in front of their

¹ <https://www.tegu.com/>

Figure 11: The figure shows the materials we used in the observational studies. In a), the magnetic blocks (Tegu) and an example of construction. In b), the pictures children replicated and in c) a child taking blocks from his/her bucket.

designated spot in the play area. The playful construction activities were as follows:

1. **Semi-open-ended play (Task 1):** Children were invited to build a given construction from an example (an image) with blocks with no time limit nor rules;
2. **Construction game with rules (Task 2):** Children were asked to replicate the constructions from an example (i.e., image). Children could pick the construction to build from six different ones. The children were asked to complete as many structures as possible within ten minutes;
3. **Open-ended collaborative play (Task 3):** Children were invited to build a construction of their choice collaboratively. No example was given, no communicated time limit (although the facilitator was instructed to stop after 10 minutes), nor rules.

Setup

The observational study was set up in a dedicated room in the school building.

In the room, we defined a communal play area. In the communal area, we placed a play mat where the playful activities took place. Children were invited to sit around the playmat in a given spot labeled with their name. In front of their area, we placed a wooden bucket with several assorted magnetic blocks. The playmat indicated where the construction should be built (i.e., construction area), namely in a middle area reachable by all the children. Around the playmat, three HD cameras recorded each child's

behaviors. The primary camera in the center of the play area recorded an overview of the activity. A camera to the right recorded the child at the left and vice versa. In another area of the room, the facilitator of the activity sat along with three researchers.

Study Protocol

A research assistant facilitated children to go through the activities and follow a study protocol. The research assistant was a Dutch-speaking female with a background in educational sciences. She was given specific instructions to interact with the children during the activity, with the main rule being to intervene as little as possible.

The protocol was as follows: When the children entered the room, they were guided to their play mat positions. They were equipped with close-talk microphones and asked whether they would agree to participation and recordings. If they agreed, we turned on the cameras to record the interaction. After that, the research assistant familiarized with the children and explained the activity. After this brief introduction, the children started to work on the *Semi-open ended play (Task 1)*.

Once children were finished with the first task (i.e., construction done), the research assistant gave positive feedback about the construction. Then, she allowed the children to deconstruct the model and explained the *Construction game with rules (Task 2)*. The children were asked to complete as many structures as possible within 10 minutes. The facilitator assessed each construction's completion, distributed the pictures to replicate (one image at a time, maximum of six pictures), and kept the time. Once the 10 minutes were up, she would communicate the "score", i.e., how many constructions were successfully done. Thereafter, the facilitator introduced the last task, *Open-ended collaborative play (Task 3)*. Once the children were finished with construction or the 5-minute mark was reached, the facilitator thanked the children for participation and took them back to the classroom.

3.2.3 *Data Analysis*

We collected around 180 minutes (3 hours) of audio-video materials and we analyzed around 103 minutes. To analyze the video-recordings we used systematic behavior analysis. Four researchers, one blind to the study design, developed an inductive coding scheme *a posteriori* the data collection. We took as unit of analysis both the triad and each child in the triad and we focused on the nonverbal behavior of the children. We used the annotation software ELAN to annotate the data, Java and Salem (a Matlab tool developed by the University of Bielefeld to analyze ELAN files) [137]. To measure an inter-coder agreement level on the categories, 15% of the data was double coded by the two independent coders, we computed Gwet's

Figure 12: In the figure, the set-up of the observational study. Three children cluster around a given area where to build a construction. The picture is taken from the audio-video recordings.

Codebook Social Behaviors		
Code	Definition	Examples of behavior
goal-directed Actions	Actions to participate and complete the tasks.	<ol style="list-style-type: none"> 1. Attaching a block with another 2. Attaching a block to the construction 3. Checking a block and compare it with the given pictures 4. Detaching a block from another 5. Detaching a block from the construction 6. Looking at a block 7. Looking at the picture 8. Picking a block from his/her own basket or the playmat 9. Putting a block down on the playmat 10. Rotating a block to find the desired position 11. Observing what other children are doing
Observation	Children observing other children's actions.	
Referential Attention	Actions to point towards an object or a person.	<ol style="list-style-type: none"> 12. Pointing to a block 13. Pointing to the construction 14. Pointing to the picture
Sharing	Actions to give/offer an object to another child.	<ol style="list-style-type: none"> 15. Passing a block another child 16. Receiving a block 17. Showing a block to offer it
Aggression	Actions to aggressively behave in the task.	<ol style="list-style-type: none"> 18. Stopping others from taking a block 19. Grasping a block from a child without permission 20. Grasping a block from a child's hand without permission 21. Grasping a block from a children's bucket without permission

Table 3: The table details the coding scheme of social behaviors we used to annotate children's behavior. As explained, we have first identified 21 physical behaviors children exhibited in the study (column examples of behavior). Then, we have cluster those behaviors in higher-level categories (column code).

AC1 [35], resulting in .701 ($p < .01$) which we deemed as acceptable to good agreement.

Coding scheme

Four researchers, one blind to the study, inspected the raw data to generate a bottom-up (i.e., inductive) coding scheme. We worked in an iterative fashion starting by familiarizing with the data and generating open codes.

Then, we identified higher level categories. Once a sufficient agreement was found, we defined a final coding scheme. Finally, three independent coders annotated the data. We annotated behaviors as occurrences (i.e., counts) and computed percentages on the counts. To better understand the prosocial and conflict dynamics, we annotate behavior sequences. To answer our research questions, we focused on prosocial and conflict behaviors, sub-group dynamics, and the occurrence of former and latter in each task. Below, we summarize the coding procedure:

1. First, we annotated the duration of each of the collaborative play tasks and discarded any other recordings (e.g., introductions and debriefing of the facilitator): resulting in 103 minutes of data to annotate.
2. Second, for each child we annotated all the observable **physical actions** per group (group from 1 to 7). We focused on physical actions (e.g., picking up a magnetic block, assembling blocks, pointing to objects) as they require less subjective inference; as a result we identified twenty-one physical behaviors (See Table 3 for an overview of the 21 physical behaviors). Annotators coded the onset and offset of the behaviors. After the first round of coding, we reflected on higher level categories for the twenty-one physical behaviors. After two iterative rounds, we identified five high-level **social behaviors** in which the physical behaviors fall: **goal-directed actions, observation, referential attention, sharing, aggression**. Table 3 summarizes the codebook we used to annotate children's social behaviors. The social behaviors we annotated helped us understand what prosocial and conflict behavior children display in collaborative play.
3. In our inspections of the data, we gathered that the **children's positions** (i.e., where the children sat and leaned towards to build the construction) in the collaborative play tasks provide insights about groups dynamic and sub-group formation. Similarly, the task position (i.e., where the main construction was build) gives indications on where the main focus of action is and where (ideally) all the children should lean towards. After many iterations, we identified seven positions children take in the corpus of data to play together. To systematically code the **task positions**, we divided the play mat in seven areas (see Figure 13). Annotators coded the onset and offset of children and task position in one area. Once children's positions were annotated, we overlapped the annotations to understand when children were clustering in sub-groups, **dyads**, or played in **triads**. We coded the rules of overlap in a script written in Java to automatically overlap annotations.
4. To understand what role children's prosocial and conflict behavior play in collaborative play, we honed in on children's sharing and conflict

dynamics. Building upon our physical action annotations, we took into account sequences of sharing and conflict behaviors. We wanted to pinpoint how prosocial and conflict dynamics unfold. To this end, we focused on children who initiate the sharing (children initiating) or conflict and the children who responded (children responding) to sharing or conflict. If a child's act of sharing is responded with acceptance (i.e., a child received the object and used it for the construction), we coded it as collaborative behavior. Instances in which a child responds without taking action, we coded it as passive stance. Conversely, if the child initiate and responded with conflicting behaviors, we label it as conflict. Table 4 summarize the sequential coding of prosocial and conflict behaviors.

Figure 13: The figure is a schematic representation of the observational study setup illustrating the positions children took during collaborative play. We identified seven areas where children sat during the tasks.

Codebook Prosocial and Conflict Sequences	
Code	Definition
Collaboration	When a child initiate a sharing behavior and a another child, the receive accept
Neglected Collaboration	When a child initiates a sharing behavior and a another child, the receiver, does not take action but only observe
Conflict	When a child grasp an object from another, while the other tries to stop him/her

Table 4: The table details the coding scheme of prosocial and conflict sequences.

3.2.4 Findings

Below, we report the findings from the observations. First, we detail our findings regarding children's behavior in collaborative play. We hone in on the sequences of prosocial and conflict behaviors. Then, we present the findings related to children's positions and sub-group formation. Lastly, we summarize how children behave and divide in sub-group per task.

Prosocial and conflict behaviors (Sub-questions 1,2)

We annotated a total of 6356 low-level physical behaviors. Counts and percentages of the annotated behaviors are summarized in Table 5.

75% of the annotated behaviors are **goal-directed behaviors**, related to building the 3D puzzle. 5% of the observed behaviors are actions to **refer the attention** of the other children to objects or people, therefore to coordinate the collaboration. 8% of the behaviors have to do with **prosocial and conflict** dynamics of collaboration, namely 3% of **sharing** behaviors and 5% of behaviors underpinning **aggression**. Surprisingly, 10% of the behaviors are children observing other children in the collaborative play task, therefore not overtly engaging in the tasks, but rather taking a passive stance.

Figure 14: Examples of goal-oriented behaviors taken from the video recordings.

Figure 15: Example of sharing behaviors taken from the video recordings.

Sharing and aggression are occurring considerably less than goal-directed behaviors, but conflict is definitely more frequent than sharing. There is a high variability in both sharing and aggression as shown in Table 5. In at least three groups, sharing behaviors represent 1% or less of the actions (Group 1, 2 and 5), in three of the other groups the percentage of sharing is between 3% and 5% (Group 3, 6, 7). Only one group show a percentage of sharing behavior of 6.97%.

For most of the groups, aggressive behaviors hover between 5% and 8,5% (Group 1, 2, 3, 6, 7) (see Table 5). Only two groups show a lower degree of aggressive behavior, namely 2.46% and 2.92%,

CHAPTER 3: BEHAVIORAL OBSERVATION STUDY OF CHILDREN’S
COLLABORATIVE PLAY AND SCENARIOS

			Goal-dir.	Share	Conflict	Ref. att.	Observation	Count
Group 1	C1	T1	49 (75.38)	0 (0)	4 (6.15)	3 (4.62)	9 (13.85)	65
		T2	51 (63.75)	0 (0)	15 (18.75)	6 (7.50)	8 (10.00)	80
		T3	24 (66.67)	0 (0)	1 (2.78)	5 (13.89)	6 (16.67)	36
	C2	T1	64 (78.05)	0 (0)	5 (6.10)	6 (7.32)	7 (8.54)	82
		T2	56 (75.68)	1 (1.35)	7 (9.46)	4 (5.41)	6 (8.11)	74
		T3	93 (90.29)	2 (1.94)	4 (3.88)	2 (1.94)	2 (1.94)	103
	C3	T1	22 (57.89)	0 (0)	1 (2.63)	4 (10.53)	11 (28.95)	38
		T2	36 (51.43)	1 (1.43)	4 (5.71)	11 (15.71)	18 (25.71)	70
		T3	36 (69.23)	2 (3.85)	0 (0)	5 (9.62)	9 (17.31)	52
Count (%)		431 (71.83)	6 (1.00)	41 (6.83)	46 (7.67)	76 (12.67)	600	
Group 2	C1	T1	39 (76.47)	0 (0)	7 (13.73)	2 (3.92)	3 (5.88)	51
		T2	111 (80.43)	3 (2.17)	14 (10.14)	4 (2.90)	6 (4.35)	138
		T3	57 (82.61)	0 (0)	0 (0)	3 (4.35)	9 (13.04)	69
	C2	T1	58 (82.86)	0 (0)	6 (8.57)	0 (0)	6 (8.57)	70
		T2	81 (70.43)	0 (0)	5 (4.35)	3 (2.61)	26 (22.61)	115
		T3	95 (94.06)	0 (0)	1 (0.99)	0 (0)	5 (4.95)	101
	C3	T1	46 (66.67)	1 (1.45)	5 (7.25)	1 (1.45)	16 (23.19)	69
		T2	77 (64.71)	4 (3.36)	9 (7.56)	2 (1.68)	27 (22.69)	119
		T3	51 (71.83)	0 (0)	3 (4.23)	2 (2.82)	15 (21.13)	71
Count (%)		615 (76.59)	8 (1.00)	50 (6.23)	17 (2.12)	113 (14.07)	803	
Group 3	C1	T1	60 (67.42)	4 (4.49)	11 (12.36)	6 (6.74)	8 (8.99)	89
		T2	41 (44.09)	7 (7.53)	3 (3.23)	22 (23.66)	20 (21.51)	93
		T3	34 (64.15)	3 (5.66)	0 (0)	6 (11.32)	10 (18.87)	53
	C2	T1	51 (61.45)	1 (1.20)	8 (9.64)	5 (6.02)	18 (21.69)	83
		T2	73 (66.36)	3 (2.73)	7 (6.36)	11 (10.00)	16 (14.55)	110
		T3	16 (55.17)	1 (3.45)	1 (3.45)	3 (10.34)	8 (27.59)	29
	C3	T1	44 (56.41)	6 (7.69)	13 (16.67)	9 (11.54)	6 (7.69)	78
		T2	126 (81.29)	6 (3.87)	14 (9.03)	3 (1.94)	6 (3.87)	155
		T3	58 (79.45)	3 (4.11)	3 (4.11)	4 (5.48)	5 (6.85)	73
Count (%)		503 (65.92)	34 (4.46)	60 (7.86)	69 (9.04)	97 (12.71)	763	
Group 4	C1	T1	41 (53.95)	8 (10.53)	0 (0)	6 (7.89)	21 (27.63)	7
		T2	78 (59.09)	13 (9.85)	3 (2.27)	4 (3.03)	34 (25.76)	132
		T3	36 (87.80)	0 (0)	0 (0)	0 (0)	5 (12.20)	41
	C2	T1	49 (55.06)	4 (4.49)	2 (2.25)	3 (3.37)	31 (34.83)	89
		T2	85 (52.47)	16 (9.88)	7 (4.32)	19 (11.73)	35 (21.60)	162
		T3	0 (0)	0 (0)	0 (0)	0 (0)	1 (100)	1
	C3	T1	111 (91.74)	5 (4.13)	4 (3.31)	1 (0.83)	0 (0)	121
		T2	190 (87.96)	16 (7.41)	9 (4.17)	1 (0.46)	0 (0)	216
		T3	47 (92.16)	0 (0)	1 (1.96)	0 (0)	3 (5.88)	51
Count (%)		637 (71.65)	62 (6.97)	26 (2.92)	34 (3.82)	130 (14.62)	889	
Group 5	C1	T1	134 (91.78)	3 (2.05)	4 (2.74)	2 (1.37)	3 (2.05)	146
		T2	148 (92.50)	0 (0)	6 (3.75)	2 (1.25)	4 (2.50)	160
		T3	88 (97.78)	0 (0)	1 (1.11)	0 (0)	1 (1.11)	90
	C2	T1	111 (87.40)	1 (0.79)	7 (5.51)	6 (4.72)	2 (1.57)	127
		T2	141 (92.76)	0 (0)	2 (1.32)	1 (0.66)	8 (5.26)	152
		T3	64 (95.52)	0 (0)	0 (0)	0 (0)	3 (4.48)	67
	C3	T1	31 (67.39)	3 (6.52)	1 (2.17)	3 (6.52)	8 (17.39)	46
		T2	133 (95.00)	0 (0)	2 (1.43)	2 (1.43)	3 (2.14)	140
		T3	41 (83.67)	0 (0)	1 (2.04)	0 (0)	7 (14.29)	49
Count (%)		891 (91.20)	7 (0.72)	24 (2.46)	16 (1.64)	39 (4.00)	977	
Group 6	C1	T1	54 (68.35)	3 (3.80)	4 (5.06)	12 (15.19)	6 (7.59)	79
		T2	150 (71.43)	7 (3.33)	22 (10.48)	15 (7.14)	16 (7.62)	210
		T3	54 (79.41)	1 (1.47)	4 (5.88)	6 (8.82)	3 (4.41)	68
	C2	T1	40 (63.49)	2 (3.17)	4 (6.35)	5 (7.94)	12 (19.05)	63
		T2	135 (72.97)	11 (5.95)	19 (10.27)	10 (5.41)	10 (5.41)	185
		T3	35 (74.47)	0 (0)	5 (10.64)	6 (12.77)	1 (2.13)	47
	C3	T1	46 (74.19)	3 (4.84)	3 (4.84)	4 (6.45)	6 (9.68)	62
		T2	88 (70.40)	6 (4.80)	9 (7.20)	5 (4.00)	17 (13.60)	125
		T3	10 (55.56)	1 (5.56)	3 (16.67)	3 (16.67)	1 (5.56)	18
Count (%)		612 (71.41)	34 (3.97)	73 (8.52)	66 (7.70)	72 (8.40)	857	
Group 7	C1	T1	90 (85.57)	4 (3.80)	8 (7.76)	1 (0.95)	2 (1.90)	105
		T2	130 (92.19)	4 (2.84)	6 (4.25)	0 (0)	1 (0.70)	141
		T3	31 (92.18)	0 (0)	0 (0)	0 (0)	2 (5.88)	33
	C2	T1	54 (71.05)	0 (0)	3 (3.95)	5 (6.58)	14 (18.42)	76
		T2	45 (55.55)	6 (7.41)	4 (9.94)	8 (19.51)	18 (22.22)	81
		T3	10 (47.62)	1 (4.76)	1 (4.76)	3 (14.29)	6 (28.57)	21
	C3	T1	53 (63.09)	5 (5.95)	6 (7.14)	8 (9.52)	12 (14.29)	84
		T2	59 (64.13)	4 (4.35)	5 (5.43)	14 (15.22)	10 (10.87)	92
		T3	3 (16.67)	0 (0)	1 (16.67)	1 (16.67)	3 (50.00)	8
Count (%)		475 (74.10)	24 (3.74)	34 (5.30)	40 (6.24)	68 (10.61)	641	
Total (%)		4164 (75.30)	175 (3.16)	308 (5.57)	288 (5.21)	595 (10.76)	5530	

Table 5: Counts and percentages of goal-directed, sharing, aggressive, referential attention and observing behaviors annotated in the study. Results are reported per task, per group and per child in the task. C1 s-stands for child 1, C2 stands for child 2, C3 stands for child 3.

Figure 16: Example of aggressive behaviors taken from the video recordings.

Resulting Category	Initiator	Reciver	Count	%
Collaboration	share	accept	86	16
Neglected Collaboration	share	observe	446	84
Tot.			532	100
Conflict	take away	stopping	48	100
Tot.			48	100

Table 6: Counts and percentages of the sequences of actions

Sequences of Actions: How Children Respond to Sharing and Aggression (Sub-question 3)

We analyzed sequences of behaviors that started with a sharing behavior or aggressive behavior (**Sub-question 3**). We analyzed 580 segments of sequence of sharing starting with sharing or taking an object to discern the response of the children. Table 6 provides an overview of the findings. 84% of the times children would respond to a sharing behavior neglecting the offer to collaborate, therefore only observing the child's offering to share the block, but not accepting the offer (Table 6). Only 16% of the times when a child offered to share a block with another child, the other child would accept, therefore collaborating with each other. In all the segments we examined, children responded to aggressive behavior (taking away an object) with an aggressive behavior (stopping the child's action), thereby entering a conflict about object possession (Table 6).

	C1 TOT	%	C2 TOT	%	C3 TOT	%	Task pos. dur. %
TASK ₁							
Task P	31	16.4	10	5	23	9	22.56
PC ₁	111	59	2	1	4	1	28.86
PC ₂	15	7.2	90	50	57	21.5	10.42
PC ₃	4	2.5	5	3	92	35	25.86
PC ₁ C ₂	23	12	21	12	8	3	5.75
PC ₂ C ₃	1	0.5	52	29	81	30.5	6.55
POUT	4	2.4	0	0	0	0	0
Total	189	100	180	100	265	100	100
TASK ₂							
Task P	81	21	21	7	54	13	33.46
PC ₁	133	34	8	2.7	5	1	15.02
PC ₂	27	7	155	52	34	8	24.29
PC ₃	13	3	8	3	204	50	14.13
PC ₁ C ₂	74	19	67	22	7	3	9.92
PC ₂ C ₃	0	0	38	13	103	25	3.18
POUT	61	16	1	0.3	1	0	0
Total	389	100	298	100	408	100	100
TASK ₃							
Task P	26	18	0	0	19	15	41.82
PC ₁	83	58	6	13	0	0	31.61
PC ₂	6	4	19	41	8	6	9.09
PC ₃	6	4	0	0	73	57	7.09
PC ₁ C ₂	20	14	7	15	5	4	6.27
PC ₂ C ₃	0	0	14	31	23	18	4.12
POUT	2	2	0	0	0	0	0
Total	143	100	46	100	128	100	100

Table 7: The table illustrates the results of the position annotations. For each of the three collaborative play tasks, we detail which position the children have taken (we do not divide all the children per group). Column one refers to the position taken by all the children assigned to C1 positions, column two refers to the positions taken by all the children assigned to C2 positions, column three refers to the positions taken by all the children assigned to C3 positions.

Sub-group dynamics (Sub-question 3)

Table 7 summarizes the positions children take during the three tasks. In general, children stayed in their assigned position or leaned towards the assigned task position (i.e., where the construction was built). They also leaned towards other children to work in dyads. The task position (i.e., where the construction was built) was situated predominantly where the task was assigned (at the center of the play mat), but in all three tasks it moved considerably, especially towards the position of one of the children taking the lead.

To understand whether children clustered in sub-groups, we analyzed the overlap of positions between the children, results are summarized in Table 8. We counted 1456 overlaps between children's positions. 57% of the

	Dyad/triad	Task 1 overlap (%)	Task 2 overlap (%)	Task 3 overlap (%)
Group 1	C1/C2	15 (34.09)	37 (50.00)	8 (42.10)
	C2/C3	17 (38.63)	7 (9.45)	7 (36.84)
	C1/C3	5 (11.36)	20 (27.02)	3 (15.78)
	C1/C2/C3	7 (15.90)	10 (13.51)	1 (5.26)
	Sum	44	74	19
Group 2	C1/C2	57 (64.04)	92 (28.75)	24 (60.00)
	C2/C3	7 (7.86)	54 (16.87)	7 (17.50)
	C1/C3	5 (5.61)	107 (33.43)	6 (15.00)
	C1/C2/C3	20 (22.47)	67 (20.93)	3 (7.50)
	Sum	89	320	40
Group 3	C1/C2	30 (24.39)	72 (29.62)	0
	C2/C3	32 (26.01)	73 (30.00)	0
	C1/C3	28 (22.76)	51 (20.98)	0
	C1/C2/C3	33 (26.82)	47 (19.34)	0
	Sum	123	243	0
Group 4	C1/C2	18 (42.85)	34 (36.95)	0
	C2/C3	9 (21.42)	37 (40.21)	2 (40.00)
	C1/C3	10 (23.80)	8 (8.69)	3 (60.00)
	C1/C2/C3	5 (11.90)	13 (14.13)	0
	Sum	42	92	5
Group 5	C1/C2	25 (71.42)	24 (88.88)	11 (78.57)
	C2/C3	4 (11.42)	1 (3.70)	1 (7.10)
	C1/C3	2 (5.71)	1 (3.70)	2 (14.28)
	C1/C2/C3	4 (11.42)	1 (3.70)	0
	Sum	35	27	14
Group 6	C1/C2	8 (50.00)	39 (97.50)	20 (41.66)
	C2/C3	4 (25.00)	0	21 (43.75)
	C1/C3	2 (12.50)	1 (2.50)	7 (14.58)
	C1/C2/C3	2 (12.50)	0	0
	Sum	16	40	48
Group 7	C1/C2	16 (30.18)	53 (44.53)	5 (38.46)
	C2/C3	20 (37.70)	22 (18.48)	0
	C1/C3	13 (24.52)	19 (15.96)	8 (51.53)
	C1/C2/C3	4 (7.54)	25 (21.00)	0
	Sum	53	119	13

Table 8: Number and percentage of overlap between dyads (C1/C2, C2/C3, C1/C3) and triad (C1/C2/C3) per group per task.

groups (i.e., 4 out of 7 groups) of children played mostly in one dyad (see Table 8). Percentages of overlap range from 42.85% (Group 3, the lowest) to 71.45% (Group 5, the highest). Three groups out of seven played mainly in two alternate dyads.

Impact of the type of task on prosocial and conflict behavior (Sub-question 4)

Children were the most active in Task 2 (Construction Game with rules) where 49,7 % of children's behaviors occurred, moderately active in Task

1 (Semi-open ended play) where 30,7% of the behaviors occurred, and the least active in Task 3 (Open-Ended Collaborative Play) where 19,9% of the behaviors occurred (See Table 5). The majority of the groups (5 out of 7) exhibited a higher number of **sharing behaviors** in Task 2 (Construction Game with Rules) and the lowest number of sharing behaviors in Task 3 (Open-ended Play). Interestingly, sharing behaviors are exhibited by all the children in the triad (3 groups out of 7) or by dyads (3 groups out of 7), rarely, only one child tried to engage in sharing behaviors (only group 2) (See Table 5).

Interestingly, all the groups show a higher percentage of aggressive behaviors in Task 2 (Construction Game with Rules), while Task 3 (Open-ended collaborative play) shows the least amount of aggressive behaviors. Within the groups, one child or a couple of children showed higher frequency of aggressive behaviors in most of the groups (5 out of 7) (See Table 5).

Looking at the sub-group formation, (62%) occurred in the second task (Construction Game with rules) (see Table 8). The first task (Semi-open ended play) and third task (Open-ended collaborative play) show less overlap (27% and 9% respectively) with the third task being the one with the least overlap between children's positions.

3.2.5 Discussion of the Findings

In this section, we discuss the findings of Study 1. First, we discuss them per sub research questions. Then, we illustrate the potential limitations of the observational study. Lastly, we articulate the design implications of the findings. Notably, we unpack how the findings impact the interventions to take in children's collaborative play, the design of the collaborative play activities, and the design of robothing's behaviors.

Sub-question 1: What Prosocial and Conflict Behavior do Children Display in Collaborative Play?

Physical actions are the main way children show prosocial and conflict behaviors in our observation of collaborative play. Most prosocial and conflict behavior have to do with the possessions of objects in the task. Nonverbal behavior such as giving an object or offering an object underpin a prosocial intention. While, taking objects from other children or stopping others from taking an object underpin an aggressive intention which might lead to conflict.

Sharing and aggression are occurring considerably less than goal-directed behaviors, but conflict is definitely more frequent than sharing. The findings are not in line with the literature on children and conflicts [319, 96] for example. The high number of aggressive behaviors seem to be unusual in elementary school children. Similarly, the low frequency of sharing behaviors and the tendency to **disregards sharing offers** appear in contrast

with the literature [97]. Typically, children would respond to prosocial behaviors of other children with more prosocial behaviors. A possible explanation for this insights is related to individual differences. Studies have shown [100] that exhibiting prosocial behavior with peers is related also to children's individual characteristics and ability to regulate socio-emotional behaviors.

Sub-question 2: What Role does Children's Prosocial and Conflict Behavior Play in Regulating Collaborative play?

Our findings show that children use prosocial behaviors and conflict behaviors to manage who uses collaborative play resources and when, and who takes the lead in the collaborative task.

We show that prosocial behaviors like sharing objects or offering objects are a way to establish collaboration to work together on the task. However, sharing is scarce while aggression is abound. Sharing offers are often refused by children, who appear to respond to prosocial behaviors like sharing with a passive stance. Conflict behaviors such as taking another child's object or stopping another child are a way to dominate another child or defend oneself. Children exhibited a large number of aggressive behaviors that underpin conflicts for the possessions of objects. Despite the fact that the children in the sample had a Montessori education background (i.e., a type of education that fosters collaborative skills since the very beginning of the school trajectory) children appeared to have difficulties in collaborating equally and sharing objects with each other. When facing aggressive behaviors, children responded back with aggressive behavior, with no or little attempt to repair. Often children took a passive stance, observing other children playing rather than intervening, somehow being excluded from the collaborative play dynamics.

Looking for an explanation in the literature, we noticed that the prosocial behaviors and conflict behavior showed by the children bear resemblance with the bid-response emotion regulatory exchange [85]. Children had three basic responses to a sharing or conflicting offer: either **turning towards another child** (accepting the offer), **turning against another child** (responding with aggression) or **turning away another child** (not accepting the offer and taking a passive stance). Hence, prosocial and conflict behaviors are exhibited in bids of collaborative offers that are accepted or not. As described by Driver and Gottman in their observations of marital conflict [85], we conclude that prosocial and conflict behaviors take a regulatory role of collaborative turn-taking.

Sub-question 3: What is the Impact of Sub-group Formation on Group Dynamics?

Our finding show that children tend to cluster in sub-groups to collaborate, working as a dyad instead of a triad. Sub-groups appear to impact the division of work, who takes the lead. In most cases one dyad dominated

the collaborative play during all the three collaborative play tasks, excluding one of the children from the collaborative task.

We also observed groups where children willingly clustered around the most active child by moving or leaning over their position. We speculate that children are attracted by the leading child and accept the leadership or try to find a way to take an active role. The findings regarding the position of the task corroborate these insights: children were building the construction either in the designated space for constructions or clustered in the space of the child or dyad who took the lead.

Therefore, we infer that sub-group formation impacts how children participate in collaborative play, creating asymmetries between children. This is in line with the literature of sub-group dynamics [329].

Sub-question 4: What is the impact of the type of collaborative task on children's prosocial and group dynamic?

The **type of collaborative task** has an impact on children's behavior too. In semi and open-ended activities, children were the least active and showed more tendency to play independently.

Collaboration and dynamics thereof (prosocial and conflict) are predominant in the collaborative game with rules. The presence of rule and a collaborative challenge enables the children to work together more and lets prosocial and conflict dynamics emerge. The open-ended nature of the other two tasks did not enable children's collaboration enough. Particularly, the only task that let the children build any construction they wanted (Task 3) showed the least number of actions and dynamics. Initially, we considered the task as an adequate setting to give the children the freedom to take control and determine the course of their own collaborative actions.

Surprisingly, from our observation this is not the case. In line with the literature related to children's creative crisis [200], when children were invited to collaboratively build a construction without rules or an example, they did not have the socio-emotional instruments to work together on a creative task.

Limitations

As with all studies, our observation has some limitations. Our chosen method, analog observation *in-the-wild* could raise concerns of low ecological validity because the researchers provide participants with the task instead of observing naturally occurring behaviors during naturally occurring activities. We mitigated this concern by (i) setting the study *in-the-wild*, a standard room of a children's school during school time, (ii) designing collaborative play tasks that resemble activities children do in their everyday life with commercially available materials, and (iii) choosing for a study facilitation style with little to no intrusion.

While guaranteeing a higher degree of objectivity and granularity, a systematic analysis focusing only on non-verbal behavior gives limited insights about why a specific behavior is exhibited. Analysis of children's conversations, speech, and natural language would provide further insights into collaborative play dynamics. However, we think that by focusing on nonverbal behaviors of children in collaborative play, an aspect often overlooked in the literature, our study addresses a gap in related work. Much of previous work has been devoted to conversation and content analysis [248, 127], with less attention to the role of nonverbal behaviors.

Despite being in line with sample sizes in developmental psychology and HCI/HRI, we know that the sample size is not big enough or diverse enough to represent the general population. Still, we believe that the study provides relevant insights into children's collaborative play.

Design Implications

The observational study has several design implications. We organize the design implications in three categories: (i) Implications for interventions in collaborative play; (ii) implications for the design of collaborative play activities and interaction; and (iii) implications for the design of robots behaviors.

1. **Implications for interventions in collaborative play:** We have shown that children in elementary school know how to collaborate, but still regulate their collaboration poorly. The regulation of collaboration appears to happen between **"bid" sequences of prosocial and conflict behaviors**. Within the "bid" sequences of prosocial and conflict behaviors, attention should be given to children's non-verbal behaviors and actions because they are the primary communication and interaction device to regulate collaboration. From what we have observed, supporting collaborative play entails intervening in these bids sequences. Bid sequences consist of nonverbal prosocial actions and conflict actions such as giving objects, offering objects, or taking objects. Therefore, if we want to promote collaboration, we would intervene to encourage prosocial behaviors and discourage conflicts in the bid sequences.
2. **Implications for the design of collaborative play activities and interaction:** We have shown that the type of game or task influences children's collaboration. From our findings, an **object-oriented game with rules** appears to be an optimal task to support children's regulation of collaboration and promote prosocial behaviors. We should design games that have clear rules and a clear goal. In so doing, we would provide a clear structure within which children can operate and divide roles and activities. Simultaneously, when designing a playful collaborative task, we should keep in mind that children tend to create

sub-groups. Children appear to assign roles for each other. In certain instances, children exclude one or more children from the game. We should design interactions that allow for sub-group formation, but encourage inclusion rather than exclusion. To this end, we should aim at re-directing children's attention and actions to the collaborative activities.

3. **Implications for the design of robot behaviors:** The findings provide some implications for possible robot behaviors. Children use goal-directed actions, observations, referential attention behaviors, sharing (i.e., giving objects), aggression (i.e., taking away an item) to engage in collaborative play. Hence, the interaction with a robot should be at the same level. Task-oriented actions could represent the main communication channel between a robot and children. How could the interaction unfold? For instance, in groups where the aggressive behaviors occur because one child takes the lead and the others do not accept this, a robot could involve all children more through **sharing objects or re-directing the attention** and to balance activity levels to reduce these tensions. A robot could also encourage collaborative actions such as exchanging blocks, like in the observation study. The robot should interact with and respond to **goal-directed actions, observation, referential attention, sharing (i.e., giving an object), aggression (i.e., taking away an object)** which are the leading nonverbal behavior children exhibits to regulate collaborative play. Interacting at the task-level to influence the social level of collaborative play brings notable challenges. It is hard for a robot to perform such actions with precision. Robot navigation in a cluttered environment is hard as well as object manipulation. Moreover, it is difficult for a robot to perceive when to intervene. It is fundamental to enable sophisticated social-signal processing to identify the nature of the bid-sequences.

3.2.6 *Study 1: Conclusions*

In this study, we sought to understand what prosocial and conflict dynamics children exhibit, the role of prosocial and conflict behaviors in regulating collaborating play, what group dynamics emerge, and how the type of task impacts children's behaviors and dynamics. This knowledge helped us identify design opportunities. We show that children find it hard to regulate the social dynamics of collaborative play. Children resort to conflict more than they show prosocial behavior. Children tend to play in sub-groups instead of playing with all the group members. The group dynamics show that children tend to dominate or exclude other children from collaborative play dynamics. We also observed that the type of collaborative play task plays a role in enabling more or less collaboration. In particular, collaborative

games with rules support the emergence of collaborative dynamics, while in open-ended tasks, children play less together.

The observational study contributes rich insights about the way children behave when engaged in collaborative play. For this dissertation, the observational study contributes insights about possible scenarios and areas of interventions to design for children's collaborative play and the socio-emotional dynamics to take into account, thereby guiding the design of the robothing behaviors.

3.3 SCENARIOS

Designing a robothing's behavior for collaborative play entails defining the situations in which a robothing interacts with children and defining the dynamics as they unfold in the interaction. Scenarios are stories about people and their activity in a specific context [48].

Scenarios do not focus on a specific interaction between interactants, but take into account the interaction dynamics as they unfold. Scenarios are vivid representations of interactive situations and possible users' experiences in the interaction. Scenarios define situations, but — at the same time — they are open-ended and easily revised. Scenarios have been used as a design tool in HCI [48], product design [11] and HRI [403] to envision the context of interaction, detail behaviors of a device, product or robot in context and specify how the interaction might unfold in context.

The Role of Scenarios

In this section, we illustrate the process of developing three interaction scenarios from the results and implications for design of Study 1 and from theory discussed in Chapter 2. First, we details the main elements of the scenarios, then we introduce three written scenarios.

3.3.1 Elements of the Scenarios

Here, we detail (i) the actors of the scenarios, (ii) describe how a robothing could intervene in collaborative play, (iii) describe the type of collaborative activities in which children and robothings interact, and finally (iv) describe child-robothings interactions and dynamics. These constitute the basic element that underpin the scenarios we developed.

- **Actors in the scenarios:** children from 7 to 11 years old are the main actors in the scenarios together with one robothing. As seen in Study 1, a triad of children show sophisticated collaborative and prosocial dynamics. One aspect stood out: children tend to play in sub-groups when playing in trios. Taking this into consideration, we decided to explore various group formations: scenarios with two children and a robothing, scenarios with three children and a robothing, and scenarios with a robothing and one child. Although some studies suggest that the gender composition of a small group of children might affect

social dynamics, we explore both the same gender and mixed gender compositions.

- **Robothing intervention in collaborative play:** In Chapter 2 we have described our envisioned robothing intervention. A robothing should show prosocial behavior in collaborative games to stimulate reciprocity and, ultimately, collaboration. In Study 1, we have observed that children's regulation of collaboration and prosocial behavior happens at the task level in bid sequences of prosocial and conflict actions (deemed as antisocial). With this in mind, we envision three ways in which the robothing can intervene in the bid sequence: two prosocial ways and one "antisocial" because we want to discern possible differences in children's responses. The robothing starts the bid-sequence by **helping**, i.e., providing relevant information to the children, **sharing**, i.e., giving useful resources to the children, or **hindering** by taking away objects to "turn against" the children.
- **Collaborative play activity:** The findings from our observation study suggest that an object-oriented game with rules would support the emergence of collaborative interaction, more than open-ended activities. Following-up on this, we devise three possible activities revolving around sorting objects in games with rules. While the presence of rules is a constant, we envision scenarios where we do not enforce collaboration. Still, we want to observe whether collaboration and prosocial behaviors would emerge in the interaction. With its focus on selecting objects and placing them in categories, sorting is an optimal vehicle of bid sequences of collaborative actions. Therefore, we focus on playful tasks that have sorting items at its core.
- **Child-robothing interactions and dynamics:** By focusing on bids of prosocial and conflict behaviors in games with rules, we imagine the child-robothing interaction will bear similarities with the child-child interactions observed in Study 1. Although our goal is to promote collaboration by stimulating prosocial behaviors, we examine all possible interaction instances. Here, we illustrate how children might react and interact with the robothing. Children might 'turn towards' the robot, accepting the robothing's help and reciprocating it. Or, children might 'turn against' the robothing refusing help and showing aggressive behavior, or they might 'turn away' from the robothing, carrying-on playing. Children may have similar responses to each other too. Children could also react by excluding the robot from the interaction, creating the sub-groups observed with children in our observation study. Potentially, children could also be confused by the actions of the robot and play independently. By exhibiting prosocial or antisocial behaviors, the robothing might bring the "norm of cooperation" in the small group or breach it. Similarly, subsequent actions of

the children in the game might swing the group norms. Depending on the robothing's behavior, children might perceive the robot having social qualities and feel more or less compelled to collaborate with the robothing and with the other children.

3.3.2 *Written Scenarios*

Taking the above elements into account, we developed three scenarios. We aim to develop ecologically valid scenarios that are instrumental in designing and evaluating a robothing's behaviors. As a result, we do not envision robothing product scenarios. We do not discuss the scenarios' implications in the broader context of interaction or the consequences of robothing interacting with other stakeholders (e.g., teachers, parents) beyond this dissertation's scope.

- **Playing a sorting game with a helpful robothing observer:** One or two children and a robothing are on the same playground. The children play a sorting game, for example, sorting chalks by color in buckets, the robothing is observing. A child needs help to find the objects because items are scattered around. The robothing provides helpful information by redirecting the attention of the child to the object the child needs. The child parses the robothing behavior and turns her attention to the item. Compelled by the robothing action, the child indirectly reciprocates the generous act with the other child.
- **Collaborating in a sorting game with a helpful robothing:** Two children and a robothing collaboratively play a tangible memory game. The goal of the game is to pair similar objects. The robothing provides suggestions in the game to inform the children of a matching move. The children play together to solve the memory game. Children follow robothing's guidance, thereby finishing the game sooner. Compelled by the robothing's helpful behavior, the children might start to collaborate more with each other.
- **Playful sorting with a prosocial and antisocial robothing:** Three children and a robothing are together on a playground to independently playing a sorting game. Everyone has a specific goal and items to sort. At one point in the game, a child needs an item that the robothing has. The robothing responds by sharing or take away objects that another child needs. The sharing behavior might start a series of direct reciprocity and indirect reciprocity dynamics. Or, conversely, the robothing behavior might be ignored by the children or sanctioned by the children.

The scenarios are an integral part of our empirical and qualitative evaluations of the robothing's behavior design (Chapter 4).

3.4 CHAPTER CONCLUSIONS

Chapter 3 focused on understanding what observable prosocial and conflict behaviors are relevant in children's collaborative play, how children's behaviors and actions unfold to regulate collaborative play, and how collaborative play tasks play a role. With this goal in mind, we have presented an observational study of small groups of children engaged in collaborative play and scenario generation stemming from the study's findings.

We learn that the regulation of collaboration among children appears to happen in between "bid" sequences of prosocial and conflict behaviors in which children show many aggressive behaviors and poor prosocial skills. Children show three primary responses to a sharing or conflicting offer: either turning towards (accepting the offer), turning against (responding with aggression), or turning away (not accepting the offer and taking a passive stance). Moreover, we learn that prosocial behaviors and conflict happen in sub-groups. Children tend to cluster in dyads and exclude other children from the task. Lastly, the type of collaborative task has an impact on children's prosocial and conflict behavior too. Games with rules appear to enable more collaborative play than open-ended activities. Thus, the findings contribute to the first question of our dissertation, namely, RQ1. *How do children regulate prosocial behaviors to collaborate in play?*

Theory and related work do not illustrate what nonverbal behaviors children display in collaborative play and how their behavior is regulated. It is often problematic for designers to understand how to envision scenarios and interaction design without in-depth knowledge of how the interaction unfolds. Basing the interaction design on children's observations instead of only theory and related work enriches our design process with ecological insights. These insights are limited to the sample, the cultural context, and the tasks we have considered. As such, they cannot be generalized to all the interactions happening in collaborative play. However, the observational study contributes to the dissertation with rich insights about how children behave when engaged in collaborative play that cannot be found in the literature, at least not at this level of granularity.

Thanks to Study 1's findings, we develop scenarios that are mindful of the way children regulate prosocial behaviors to collaborate in play. The scenarios revolve around sorting games in which a robot intervenes in bid sequences displaying prosocial behaviors to – in turn – stimulate children's prosocial behavior and ultimately collaboration.

All in all, Chapter 3 contributes to this dissertation with foundational knowledge about the prosocial, conflict, and collaborative dynamics of children engaged in collaborative play that guide the interaction design effort. The knowledge gathered in this chapter helped us define the type of intervention and context of intervention, offering concrete narratives to design robot's behaviors.

“To complicate is simple to simplify is complicated. Everybody is able to complicate. Only a few can simplify.”

Bruno Munari (1966)^a

^a I suggest to listen to **10 Midi** and **Two Thousand Seventeen** by Four Tet while reading this chapter.

Chapter 4 focuses on how robothing behaviors can be designed to communicate to children without human-like appearance, modalities and/or behaviors. According to the framework presented in Chapter 2, robothings should be designed to communicate in ‘human terms’, that is to leverage the human tendency to perceive self-propelled objects that behave in contingent ways as agents and infer their intention solely from movements and actions. To this end, we explore non-verbal modalities, like a robothing’s minimal motion, locomotion, actions and non-verbal sounds to communicate sharing, helping, and taking intentions in collaborative play. Chapter 4 details findings from empirical evaluations of the behaviors (Study 2, Study 3) and a longitudinal case-study (Study 4), which show that it is possible to legibly communicate a robothing’s intention only with minimal motion (gaze-movements), locomotion and actions like nudging and giving or taking away resources. Motion and action appear to override non-verbal sounds too. Moreover, our case-study provides first indications that robothings have an effect in collaborative play dynamics: robothings influence children’s social motives to collaborate with one another and reciprocate one another in collaborative play.

The chapter is based on the following publications:

Zaga, C., de Vries, R. A., Li, J., Truong, K. P., and Evers, V. (2017, May). A simple nod of the head: The effect of minimal robot movements on children’s perception of a low-anthropomorphic robot. In *Proceedings of the 2017 CHI conference on human factors in computing systems* (pp. 336-341)

Zaga, C., De Vries, R. A., Spengelink, S. J., Truong, K. P., and Evers, V. (2016, March). Help-giving robot behaviors in child-robot games: Exploring semantic free utterances. In *2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)* (pp. 541-542). IEEE.

Zaga, C. (2017, March). Something in The Way It Moves and Beeps: Exploring Minimal non-verbal Robot Behavior for Child-Robot Interaction. In *Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction* (pp. 387-388)..

Zaga C., Truong K.P., Kim J., and Evers V. D2.2 Report on design of game for long-term involvement of multiple children, Long-term children-robot interaction, Squirrel (Clearing Clutter Bit by Bit), Public Deliverable, Technical Report University of Twente (Vienna, March 2018).

4.1 CHAPTER INTRODUCTION

When we interact with one another, we need to understand each other's actions and share intentions to know what actions to take next [361]. A similar process happens with artificial agents such as robots. While humans have a psychological infrastructure to parse actions to understand intentions and conventional non-verbal (gestures) and verbal (language) ways to communicate and interact, robots do not.

*The status quo in HRI
and the challenges*

*Going beyond
human-like robot
behaviors: motivations*

In Chapter 2, we explained that a robot with less human-like form, role and behaviors might mitigate these effects and achieve more appropriate child-robot interactions. We propose robthings, hybrids of social robots and objects that interact only non-verbally and through play, to influence children's collaboration and prosocial behavior in collaborative play. But, how would a robothing communicate without a full human form, modalities and behaviors?

In our framework (Chapter 2), we propose that a robothing should communicate in "human terms" rather than in human-like ways. Without codified or conventional communication, even abstract objects can communicate intention and engage in interaction [142]. We focus on non-verbal communication, actions and cues to ease people's understanding of an agent's intentions. However, many questions remain. A designer needs to be able to translate a complex mechanism of social communication into actionable guidelines for design: How should the non-verbal behavior of low/non-anthropomorphic robots be designed to communicate a robot's intention to children? Behavior design influences interaction design. A prerequisite to an effective interaction is a correct interpretation of the intended meaning of a behavior [240]. Depending on the interpretation, children will respond accordingly. Should the interpretation be incorrect, the robothing

Robthing Behaviors	Modalities	Designed as
social gaze-movement	rotation of the base	minimal shifts (right or left) within an angle of 30 to 120 degrees aligned to and following face and body orientation of the children
deictic gaze-movement	rotation of the base	minimal shifts (right or left) within an angle of 30 to 120 degrees oriented to an object
help-giving	locomotion, SFU	forward locomotion and nudging of an object
sharing	locomotion	forward locomotion and dragging/pushing of an object towards a child
taking away	locomotion	forward locomotion and dragging/pushing of a object away from the child

Table 9: The table summarizes the prototype of robthings behaviors designed according to our framework. For each behavior modalities and design is detailed.

Figure 17: The figure describe the steps we take in the design's process of Part I, and hones-in the structure of Chapter 4.

intervention might fail. Only when the communication of the robothing's social motive is clear, children can collaboratively engage with the robothing, possibly reciprocating the robothing's acts behaving prosocially in collaborative play. How do children interpret and perceive the non-verbal behavior of low /non-anthropomorphic robots in play, then? Once communication between a child and a robot is achieved, a robot sorts effect on children's behaviors. What are the effects of a robothing behavior on the prosocial behavior and collaboration of children in play?

Overview of the Chapter

This chapter tackles the research questions described in Chapter 1 (RQ3, RQ4, RQ6). We investigate how to design a robothing's behavior to communicate in human terms to children in collaborative play. A prerequisite for a robothing to intervene in children's collaborative play is to clearly communicate the robothing's social motive underpinning its behaviors and actions. Drawing from Chapter 3 (**Study 1**) and the **interaction scenarios** we have developed and Chapter's 2 conceptual framework and design principles, we design a series of non-verbal behavior for existing robothing's platforms (i.e., gaze-movements, locomotion with nudging, semantic free utterances, sharing and taking away through locomotion, see Table 9), the Festo Robotino and the Squirrel robot. We evaluate the robothings' behavior prototypes in empirical and qualitative studies. **Study 2** reports a video-based HRI experiment in which we investigate children's understanding of a robothing's minimal gaze-movements. **Study 3** reports an exploratory HRI experiment to examine how semantic free sounds support the communication of a robothing's help-giving in collaborative play. Finally, **Study 4** reports a longitudinal case-study to explore the influence of robothing's behaviors on children's reciprocity. We conclude the chapter with a reflection on the findings.

4.2 STUDY 2: CHILDREN’S UNDERSTANDING OF MINIMAL ROBOTHING’S GAZE-MOVEMENTS

This section presents a video-based HRI (VHRI) study to evaluate how our prototypes of minimal gaze-movements are understood by children and how children perceive the robothing’s gaze movements. We designed two types of minimal gaze movements: *social-gaze movements* to communicate social engagement and *deictic-gaze movements* to communicate task-related referential information.

In a two (social-gaze movements vs. none) by two (deictic-gaze movements vs. none) video-based study ($n=72$), we found that social-gaze movements significantly increased children’s perception of animacy and likeability of the robot. Deictic-gaze and social-gaze movements combined significantly increased children’s perception of helpfulness. Our findings show the compelling communicative power of minimal gaze movements — which were legible to children and impacted their perception of the robothing. Our results have implications for designers who want to achieve animacy, likeability and communicate complex intentional attributes of a robothing, like helpfulness, with simple and easily implementable minimal robot movements.

Our work contributes to human-robot interaction research and design by providing a first indication of the potential of minimal robot movements to communicate social engagement and helpful referential information to children.

4.2.1 Introduction

Research has shown that robots hold tremendous promise for children’s education and socio-emotional development [25, 189, 235, 354] paving the way not only for research, but also for consumer robots for children. While the application domains vary — from educational learning like the Dash and Dot Robots¹ to child therapy with the Leka Robot² – common attributes of these robotic products are simple aesthetics, minimal actuation, and non-verbal communication.

State of the World and
Motivation

Robots designed for children that do not fall in the classic humanoid shape and that rely on non-verbal behavior have clear design advantages: (i) children’s expectations of interaction [25] are minimized (e.g., a humanoid face might raise the expectation that the robot is able to understand and produce natural language which is often not the case [409]), (ii) robustness and reliability of the robotic system *in the wild* is maximized (e.g., robot-limb-based locomotion can be complex and is rarely reliable outside laboratory and industrial settings), and (iii) the Uncanny Valley effect is avoided [256,

¹ <https://store.makewonder.com/>

² <https://www.indiegogo.com/projects/leka-an-exceptional-toy-for-exceptional-children-autism#/>

352]. However, limiting the anthropomorphic robot appearance and reducing the range of communicative modalities available has the disadvantage of leaving interaction designers with fewer degrees of freedom to work with to design robot behaviors that readily communicate to people at large and children in specific.

Increasingly, a solution to this disadvantage is to carefully design non-verbal behavior that *'buys the designer valuable expressive power of which other aspects of the robot's design can be relieved'* [151]. In other words, HRI researchers are exploring ways to go beyond human-like robot communication, and in doing so, go beyond robots' human-like form and modalities to communicate.

Two crucial open questions for interaction designers are *how* to design non-verbal robot behavior for low-anthropomorphic robots to legibly communicate their goals and intentions without human-like communication and *what effect* will the robot's behavior have on the user's perception of the robot: will the robot behaviors still convey the meaning that is intended? This holds particular importance in child-robot interactions (cHRI), as children bring unique challenges related to the attribution of agency and perception of interaction affordances [178, 362] (see Chapter 2).

The focus of the Study

In our research we explore how low to non-anthropomorphic robots, i.e. "robothings", can communicate in *human terms*, instead of communicating in *human-like* ways to children. (as explained in Chapter 2).

Specifically, we investigate how a low-anthropomorphic robothing's movements signal a helpful communicative act in joint tasks. We focus on movements that signal to the person or agent the subject of a communicative act, which are movements that say *'I am directing my attention to you'* and movements that signal to the reference of a communicative action to provide helpful information *'I would like to draw your attention to this object/situation'* [361]. According to Tomasello's seminal work the Origins of Human Communication [361] (for a review see Chapter 2), when such movements are set up in a clear joint attentional context where all subjects and objects of communication are readily available to both interactants, even minimal movements can communicate complex motives, enabling interactants to infer the communicator's underlying social intention.

With this in mind, we designed *social-gaze movements*, synchronous movements shifting toward the interaction partner to signal attention. To provide helpful task-related referential information, we designed *deictic-gaze movements* shifting the robot's body orientation to an object of interest for the task.

We investigated how well children can understand the two gaze movements (i.e., legibility), how the gaze movements influence children's perception of animacy and likeability of the robothing's behavior, and how helpful children perceive the robothing's gaze-movements to be in a VHRI study. Drawing from literature [10, 224], we expect that:

1. **H1:** Minimal robot movements resembling social gaze will increase children's perception of animacy (H1a) and likeability (H1b) of the robot;
2. **H2:** Minimal robot movement resembling deictic gaze will increase children's perception of helpfulness (H2a) of the robot, and will increase the effect of children's perception of social-gaze movements on animacy (H2b) and likeability (H2c) of the robot.

The study

In a two (social-gaze movements vs. none) by two (deictic-gaze movements vs. none) video-based study ($n=72$), we found that children find both social-gaze movements and deictic-gaze movements legible and that the gaze-movements are perceived as helpful by children.

In particular, social-gaze movements significantly increased children's perception of animacy and likeability of the robothing. Both, deictic-gaze and social-gaze movements significantly increased children's perception of helpfulness of the robothing, especially when the two gaze-movements are combined.

Our findings show the compelling communicative power of social-gaze movements, and to a lesser extent deictic-gaze movements. Minimal gaze-movements of a robothing are sufficient to achieve animacy, likeability, helpfulness and communicate the robothing's goals.

Our work contributes to HRI research and design by providing a first indication of the potential of minimal robot movements design to communicate social engagement and helpful referential information to children in collaborative play settings in human terms. Moreover, our findings lay the ground work for investigating minimal movements as communicative acts for low and non-anthropomorphic robots to communicate in human terms.

4.2.2 *Related Work in HRI and cHRI*

Researchers have been exploring design solutions for non-verbal communication of low and non-anthropomorphic robots by focusing on communicating with body movements, gaze and other non-verbal behaviors.

Robot Movements

Body movements and locomotion enable low-anthropomorphic robots to communicate their intentions, internal states, and emotions, contributing to people's comprehension and acceptance of the robot [151, 204, 207, 299]. Recent studies have found that simple non-anthropomorphic motion of a robot can influence behaviors and interpersonal dynamics [184, 153, 299] and communicate complex traits of robots [228].

Ju and Hoffman [151] showed the importance of expressive movements for robot communication in various studies, opening venues to design non-anthropomorphic robots starting from their movements. Takayama et al. [356] demonstrated that by adding simple movements displaying forethought and reaction, the readability and fluency of human-robot interaction

was increased. In a similar vein, Sirkin et al. [333] unveiled how robot movements alone are sufficient to convey intention and coordination of joint actions. Fink et al. [105] evaluated the interplay between reactive and proactive engagement-seeking movements, sounds and lights for a robotic toy box to motivate young children to tidy up their room. Interestingly, the proactive non-verbal behaviors were less effective than the reactive ones, distracting the children from the tidying up activity.

Gaze is a powerful non-verbal behavior that greatly supports human-agent interaction [9, 44, 113, 257]. Even though eye gaze and head gaze can be challenging to realize in robots without a clearly distinguishable head and actuated eyes, there is evidence that the communicative power of gaze can also be achieved in low-anthropomorphic robots. For example, results on the role of affiliative and referential gaze from literature on virtual agents [10] can be reproduced in non-humanoid robots. In fact, Lehmann et al. [224] showed that a low-anthropomorphic robot's gaze-shift-like movements synchronized with a user's movements positively shaped the interaction in an object-oriented task.

It is fundamental that the robot motion is understood by people. Researchers have used various measures to evaluate whether a robot's movement is read and interpreted as intended, but there is not yet consensus on how to evaluate the understanding and perception of robot motion, especially for children. Children have "animism" tendencies, blurring the boundaries between animate and inanimate more than adults do [3] (see Chapter 2 and Chapter 5). It is therefore imperative to understand how a low-anthropomorphic robot's movements communicate to children because children's interpretations of a robot's behaviors might deviate from what designers expect in significant ways [25].

Building upon the research of action explanation in psychology, HRI scholars have used measures for animacy and legibility. Animacy refers to the perception of an object as an animate autonomous agent and represents a prerequisite to attribute states and qualities to a robot, mapping onto concepts of agency and perceptual causality [250]. Animacy is one of the crucial features for children to understand that an object that moves autonomously is an agent [52, 268] with goal-directed behaviors. Animacy very much influences children's perception of an agent's intention and goal-directness [286]. Currently, only a few instruments have been developed in HRI to measure animacy, notably the "Godspeed Questionnaire" [19], but no instrument has been developed specifically for children.

Legibility has been formalized in HRI by Dragan [83] as: reading the goal of a behavior from the movement. Legibility thus refers to the ability of people to read the underpinning goal of a robot movement, thereby kick-starting the process of behavior explanation [240] that guide people to take action according to their understanding of the goal and intention of a robot. Despite the importance of legibility, validated measures to evaluate legibility

*Understanding Robot
Movement
Communication*

are not yet available and most scholars use measures from psychology, such as open “what” and “why” questions.

Conclusions

To conclude, the HRI research regarding non-verbal communication shows the potential of robot movements to be full communicative acts that impact interactions even without human-like behaviors and form. Gaze in particular has the potential to be rendered in low-anthropomorphic robots retaining its communicative power. However, related work shows that there is not a comprehensive understanding of how movements of a low or non-anthropomorphic robot will clue humans into understanding goals and intentions of a robot and what actions and interactions are possible. Especially, little is known about how gaze movement of a low-anthropomorphic robot can readily communicate to children. Evaluating the legibility and perception of animacy of a low-anthropomorphic robot behavior is thus imperative.

4.2.3 *Methods*

From a methodological perspective, our research follows a combination of human-robot interaction (HRI) design methodologies that have been shown to yield impactful findings [151, 332, 347], also with our population [268]. Our approach is to evaluate our designs in video-based studies and follow-up with *in-person* and *in-situ* behavioral studies.

In this VHRI study, we exposed children to videos of a robot’s social-gaze and deictic-gaze movements to evaluate children’s legibility of the robot behaviors and children’s perception of animacy, likeability and helpfulness of the robot’s behavior. To test our hypotheses, we conducted a two (social-gaze movements vs. none) by two (deictic-gaze movements vs. none) between-subjects video HRI experiment.

We manipulated social-gaze movements and deictic-gaze movements of the robot between subjects. The resulting conditions are: (i) *social and deictic-gaze movements condition* (i.e., the robot exhibited social-gaze movements since the beginning of the sorting task and the deictic-gaze movements only to indicate where the missing chalk is); (ii) *social-gaze movements condition* (i.e., the robot exhibited social-gaze movements from the beginning of the sorting task and does not exhibit deictic-gaze movements to indicate the missing chalk); (iii) *deictic-gaze movements condition* (i.e., the robot only ‘pointed’ at the missing chalk) and (iv) *static condition* (i.e., no social nor deictic-gaze movements).

Participants

The study was conducted with 72 participants recruited among 4 classes coming from international elementary schools in Manchester (UK) and Hengelo (NL), where the language of instruction is English. Their age ranged between 8 and 12 years ($M = 9.63$, $SD = .95$, $Median = 10$); 55.6%

Figure 18: Figure a) the robot and the actor at the beginning of the playful sorting task; b) the robot exhibiting social-gaze movement towards the actor; c) the robot exhibiting deictic-gaze movement to provide helpful referential information.

of the participants were female ($N = 40$, $M = 9.75$, $SD = .92$, $Median = 10$) and 44.4% was male ($N = 32$, $M = 9.47$, $SD = .98$, $Median = 9$). 81% of the participants had seen a robot in real life before and 55.6% reported to have played at least once with a robot.

Ethics

The study was approved by the Ethical Committee of the University of Twente. The participants' legal tutors (e.g., parents, relatives) and teachers were provided with informed consent before the study. All children participants gave verbal assent to participation. At the end of the study, children were debriefed regarding the scope of the study and the robot's autonomy.

Robothing and Robothing Behaviors

The robot used is a Festo Robotino³, a mobile robotic system with three omnidirectional wheels. The robot is covered with a low-fidelity Styrofoam semi-spherical shell. The only anthropomorphic element is a white sphere with a black dot that resembles an eye, not actuated. The robot only rotated (1 degree of freedom).

In our scenario, the robot interacted with an actor during a playful sorting task, i.e., sorting chalks by color (See Chapter 3) for details about the rationale of the chosen scenario). As the robot could not fully participate in the object manipulation task (it does not have arms or grippers), we framed its role as a reactive, but engaged co-player. The robot exhibited social engagement in the playful task by attentively following the co-player's actions (i.e., social-gaze movements) and provided helpful referential information for the completion of the task (i.e., deictic gaze), by '*pointing*' at the location of the last missing chalk outside the co-player's field of vision.

To design social-gaze and deictic-gaze movements, we used solely motion. The minimal robot movements consist of lateral shifts of its base, adapted to the degree of freedom of the robot. The resulting robot behaviors included whole-body (i.e., robot base) shifts (right or left) within an angle of 30 degrees to maximum 120 degrees. Social-gaze movements are devised as robot base

³ <http://www.festo-didactic.com/int-en/services/robotino/>

Animacy items	
Please, rate how the robot was	
Artificial	- Lifelike
Inert	- Interactive
Apathetic	- Responsive
Likeability items	
Please rate how the robot was	
Unfriendly	- Friendly
Unkind	- Kind
Awful	- Nice
Helpful Item	
How helpful do you think the robot was?	
Not helpful at all	- Very Helpful

Table 10: The table illustrates the Animacy, Likeability and Helpfulness items. Animacy and Likeability items are taken from the Godspeed questionnaire, a 5-point semantic scale. The Helpfulness item is a 5-point Likert scale item, presented to the children with 5 smileys instead of numbers. We used the validated instrument Smiley-o-meter [288, 243].

shifts aligned to the actor and following face and body orientation of the actor throughout the task (i.e., looking where the actor is looking). They are movements that signal to the children the subject of a communicative act, which are movements that say ‘*I am directing my attention to you*’. As one of the important elements of communicating in gaze-like ways is timing [224] we explored shifts (right or left) within an angle of 30 degrees to maximum 120 degrees to align to the children and follow face and body orientation of the children throughout the interaction (i.e., to simulate looking where the child is looking). The social-gaze shifts start with a minimal latency when the actor moves her head or arm. They are timed to be synchronous and they are contingent on the actor’s actions (i.e., robot follows the movements and actions of the actor, generating the impression of being socially engaged).

The robothing needs to clarify the object of the communication. Referring to objects disambiguates important information in the context of collaborative play. The communicative goal of referring to an object is to signal that ‘*I would like to draw your attention to this object/situation*’ [361]. Referring to an object is a form of deixis [131]. Deixis refers to words and phrases, such as “you” or “there”, that cannot be understood without information about the context. Deixis refers to actions too. We designed minimal movements, deictic gaze movements devised as robothing base shifts oriented towards an object. In our case, the robot points once towards the last chalk at the end of each sorting task session (Figure 18b, 18c).

Video Stimuli, Setup and Procedure

We asked each participant to watch a 1 minute movie of the above described scenario and to respond to an online questionnaire on Survey-Monkey⁴ administered via tablet computers.

In the video, a female actor sits in front of a grey mat where colored chalks were (seemingly) randomly scattered next to three colored baskets (Figure 18a). The robot is positioned on the opposite side of the mat facing the actor and it was controlled remotely by another researcher. We chose the same camera perspective as [224], i.e., over-the-shoulder of the actor (only arms and back of the head visible) to minimize the 3rd person perspective [309].

Participants received a brief introduction, thereafter they were randomly assigned to one of four experimental conditions, which resulted in sub-sample sizes of $n = 17$ for social and deictic-gaze movements, $n = 19$ for social-gaze movements, $n = 19$ for deictic-gaze movements, and $n = 17$ for the static condition. Each participant sat at a table equipped with a tablet, i.e., Apple iPad, with the browser open on the questionnaire page. An activity facilitator was instructed to support the participants in case of problems and to debrief them upon completion of the questionnaire.

Measures and Data Analysis

We measured the legibility of the robot behavior through a single multiple choice item (i.e., a factual question about how the children understood the robot's behavior). The question served the purposed of manipulation check too (See Manipulation and legibility check subsection).

Together with animacy, we measured likeability of the robot because we would like to understand if the behaviors of the robot are seen as kind, friendly, likeable, which are potential attributes of a robot like ours, a robot that provides helpful information [19, 25]. Both constructs are measured via related items of the validated Godspeed questionnaire [20]. We measured **helpfulness** since we have designed social and deictic-gaze movements to communicate that the robot is performing helpful actions in the playful task.

We measured perception of animacy and likeability with three items for each construct (both constructs reach high reliability, Cronbach's alpha animacy = .77, and likeability = .88) of the corresponding dimension of the Godspeed questionnaire [19], an HRI validated measure of participants' perceptions in a semantic scale.

We designed a 5-point Smiley-o-meter [288] scale-item like [233] (*How helpful do you think the robot was*) anchored from *Not helpful at all* to *Very Helpful* to assess the perception of helpfulness of the robot. We also collected demographic information on age, gender, and prior experience with robots (one item each).

⁴ <https://www.surveymonkey.com/>

Legibility and Manipulation check

To check the manipulation of social-gaze and deictic-gaze movements a single multiple choice item (i.e., a factual question about how the children understood the robot's behavior) was inserted. This question also allowed us to assess the legibility of the robot's behavior in the scenario. The item was: *What do you think the robot was doing? a) The robot was only pointing at the missing chalk, b) The robot was following what the person was doing and pointing at the missing chalk, c) The robot was standing still doing nothing with the person, d) The robot was only following what the person was doing.* The manipulation was successful. Children were able to read the goal of the robot with high accuracy, 97 % of the participants recognized the underlining actions in the social and deictic-gaze movements condition, 98% for the social-gaze movements condition, 97 % for deictic-gaze movements, and 99% for the control condition in which the robot was not moving. Participants were able to correctly recognize the goal of the actions underlying the robot's minimal gaze movements above chance ($\chi^2(d = 9) = 145.166, p < .001$).

4.2.4 Results

A two-way analysis of variance (ANOVA) was conducted to evaluate the effects of social-gaze and deictic-gaze movements on children's perception of animacy, likeability and helpfulness of the robot.

Perception of animacy

The results of perception of animacy of the robot support H1a, but they only partially support H2b. We found an interaction effect of social and deictic-gaze movements on the perceived animacy of the robot ($F(1, 68) = 7.168, p = .009, \eta^2 = .005$). Simple effect analysis of social-gaze movements shows that social-gaze movements play a great role in the perception of the robot as 'life-like' and 'socially engaged'. Social-gaze movements significantly ($F(1, 58), p < .001, \eta^2 = .042$) contribute to the perception of animacy both in combination with deictic-gaze movements ($m = 3.75, sd = 0.68$) or not ($m = 3.68, sd = 0.64$). However, simple effect analysis of deictic-gaze movements show that they do not play a significant role in the perception of animacy (i.e., no significant difference).

Perception of likeability

The results for perceived likeability support H1b, but not H2c. We found no interaction effect of social-gaze and deictic-gaze movements on perceived likeability of the robot. We found that social-gaze movements ($F(1, 68) = 4.847, p = .031, \eta^2 = .06$) had a main effect on the perceived likeability of the robot, which significantly increased (social gaze: $m = 4.17, CI[3.922 - 4.409]$; no social gaze: $m = 3.79, CI[3.542 - 4.029]$), while deictic-gaze movement

Figure 19: The interaction effect of social and deictic-gaze movements on perceived animacy of the robot. Error bars are standard deviations.

did not have an effect on likeability, even though deictic-gaze movements were expected to contribute to the perception of likeability by delivering referential information in the task.

4.2.5 Perception of Helpfulness

The results of perceived helpfulness support H2a, but present an additional result. We found no interaction effect of social-gaze and deictic-gaze movements on perceived helpfulness. From main effect analysis though, deictic-gaze movements (hypothesized) and social-gaze movements (not hypothesized) both had a main effect and increased the perception of helpfulness of the robot (social gaze; $F(1) = 43.811$, $p < .000$, $\eta^2 = .33$ no deictic gaze: $m = 2.90$, $CI[2.637 - 3.156]$, deictic gaze: $m = 4.12$, $CI[3.855 - 4.374]$, deictic gaze; ($F(1) = 5.427$, $p = .023$, $\eta^2 = .004$ no social gaze: $n = 3.29$, $CI[3.031 - 3.551]$, social gaze: $m = 3.72$, $CI[3.406 - 3.908]$). From pairwise comparison and estimates analysis, we found that deictic-gaze movements are fundamental to perceive the robot as helpful, but it is when deictic-gaze and social-gaze movements are combined that perceived helpfulness increases the most (i.e., yields the highest rating for perceived helpfulness, $m = 4.12$, $CI[3.855 - 4.374]$).

4.2.6 Discussion

Our findings show that minimal robot social-gaze movements and deictic-gaze movements communicate social engagement and helpful referential information to children. Children were able to accurately understand the

Figure 20: The main effects of social-gaze movements on perceived likeability of the robot. Error Bars are standard deviations.

Figure 21: Main effects of social and deictic-gaze movements on perceived helpfulness of the robot. Error bars are standard deviations.

legibility of the minimal game-movements of the low-anthropomorphic robot, without human-like form or behaviors. In line with the HRI literature on robot movements and with the literature that underpins our framework to design robthings, we show that the minimal robot's gaze movements affect children's perception of animacy, likeability and helpfulness. Specifically, we found that the perception of animacy and likeability significantly increases with social-gaze movements, but not with deictic-gaze movements. Although perception of helpfulness significantly increases with deictic-gaze movements, it is when both deictic and social-gaze movements are used that perceived helpfulness increases the most.

Social-gaze movements deliver social engagement in a task and have a compelling communicative power. They can be employed, alone or in

combination with other minimal movements (in our case, deictic gaze), to achieve animacy and influence likeability of the robot and the perception of traits of the robot (in our case helpfulness). Social-gaze movements potentially enable a set of easily implementable robot behaviors for low-anthropomorphic robots: simple rotation of the base can communicate that the robot is directing the attention to a subject. Our results on social-gaze for low-anthropomorphic robots are in line with results in the literature [373], but they go a step further as they exemplify that simple rotation of the base of a robot is enough to communicate attention to a subject and this can be combined with other movements to achieve communication. Deictic-gaze movements deliver task-related referential information and affect the perception of helpfulness, but to reach the maximum effect on perception of helpfulness, designers should combine social and deictic-gaze movements. Moreover these findings lay the ground for *in-person* follow-up studies. Building upon our results, we will hone in on children's behavioral responses to social-gaze and deictic-gaze movements in collaborative play.

Limitations

The study has some methodological limitations. Although adopting a VHRI method might pose some limitations (e.g., ecological validity and reliability of the results) [351], a large number of studies have shown that VHRI studies yield similar results as live HRI [224, 268, 347, 356, 401].

We chose a methodology that allowed us to address our hypotheses in a more controlled way. VHRI guaranteed uniformity of the stimuli and we can be relatively certain that the effects obtained are caused by our experimental variables and not by contextual factors, resulting in high internal validity. In addition, VHRI allowed us to reach a relatively large sample size, which is uncommon in cHRI [25].

Despite the fact that VHRI normally allows researchers to examine large design spaces with many variables, we investigated only a limited set of variables and measures that were instrumental to our investigation. We believe that this adds to a higher reliability of children's responses, as for children it is often hard to understand and differentiate between too many constructs [243].

Another potential drawback of VHRI is that participants did not experience a live robot, but a video from a 3rd person perspective [309]. Despite the fact that 3rd person and indirect interaction appear to yield reliable results in cHRI [268], we carefully mitigated 3rd person perspective drawbacks by using an over-the-shoulder camera view: participants were able to focus on the robot, not distracted by contextual information (e.g., actor's age, gender or ethnicity). This was also expected to address the limited immersiveness [171] of VHRI.

We focused the scope of our VHRI study to our robot platform, but it is possible that our minimal movements can be adapted to other platforms by

virtue of their practicality and simplicity for robot design. We focused on children, however, we imagine that adults could also respond to minimal robot movements in a similar manner, by virtue of the simplicity of the movements. Additionally, we have tested only with children living in Europe. Although the body of literature that is at the foundation of our design framework indicates that non-conventional movements and gestures are potentially universal [361], cross-cultural studies are needed to have a more comprehensive picture of the communicative power of minimal gaze-movements in different cultures. We leave empirical evaluation of this as future work.

Another potential limitation, is the chosen appearance of the robot: appearance and behaviors often have interplay effects [151]. We wanted to give a clear distinction of the front and back of the robot and we have chosen a non-actuated ping-pong ball for that purpose. Although the robot is low-anthropomorphic and the motion is not human-like, the dummy eye might have created the illusion of a human-like gaze. We do not anticipate a large confound as based on literature [142], we posit that the motion has had a higher impact rather than the appearance. Recent studies by other authors that build upon our work, have shown similar result with an even less anthropomorphic robot [8]. Nevertheless, we will test whether an even more abstract appearance will yield similar results (see Chapter 7).

4.2.7 *Conclusions Study 2*

In this VHRI study, we explored the design of minimal robot movements resembling social and deictic gaze. We evaluated the legibility of the gaze-movement and how this affects children’s perception of animacy, likeability and helpfulness of the robot’s behavior. The video study presented in this section lays the groundwork for more design exploration around simple roboting movements that signal (to child and robot) a helpful communicative act in a joint attentional context.

Our findings contribute to HRI and design literature by showing the potential of minimal robot movements to communicate social engagement and helpful referential information. In particular, social-gaze movements and to a lesser extent deictic-gaze movements, have compelling communicative power, positively affecting children’s perception of animacy, likeability and contributing to the perception of helpfulness of the robot.

The results of the study inform subsequent studies of this dissertation in Chapter 4, 7, and 8. We provide initial positive indications that it is possible to legibly communicate a roboting’s goal in collaborative play only with minimal motion and simple actions that are communicating in human terms, leveraging the human psychological infrastructure of intention sharing. For a roboting to readily communicate goals and intentions in a task is the prerequisite to the roboting intervening in collaborative play, which is the ultimate goal of the dissertation (see Chapter 2).

4.3 STUDY 3: EXPLORING SOUND TO COMMUNICATE A ROBOTHING'S
HELP-GIVING

In this section, we report on an exploratory in-person HRI study on the use of Semantic Free Utterances — vocalizations and sounds without semantic content — to communicate a robothing's help-giving to children in collaborative play. This dissertation mainly focuses on robothings' movements, in particular locomotion, and actions to communicate in child-robot interactions. However, literature shows that sounds and vocalizations are often used to reinforce and support the communication of underlying intentions of actions. Therefore, sounds and vocalizations combined with a robothing's movements and actions could contribute to an enhanced child-robot communication.

We present initial findings from an experiment where we used Semantic Free Utterances as an alternative to Natural Language to reinforce the meaning of an action in a child-robot collaborative game. We tested (i) if two types of Semantic Free Utterances could be accurately recognized by the children; and (ii) what effect the type of Semantic Free Utterances had as part of help-giving behaviors with *in situ* child-robot interaction.

We discuss the potential benefits and pitfalls of Semantic Free Utterances for child-robot communication. Whilst results regarding gibberish speech, one of the two types of Semantic Free Utterances tested, are promising, we conclude that a robothing's motion and actions alone sufficiently communicate intentions to children.

4.3.1 Introduction

Before humans started communicating with natural language, actions and non-codified gestures were the main modes of human communication [361]. Non-verbal sounds and vocalizations often times accompanied actions to strengthen or disambiguate actions' meaning [34]. For example, the combination of vocalizations and actions is profusely used by infants to give urgency to a gesture, for example a pointing gesture with point-accompanying vocalizations provide clues to parents of the infant's underlying intentions when pointing [132].

How could sounds and vocalizations be used in a similar manner for robot's movements and actions? How could sound and vocalizations be used in combination with a robot's action to legibly communicate goals and intentions non-verbally? The verbal channel represents the predominant communication modality in child-robot interaction (cHRI). At the same time, verbal communication between children and robot is problematic [195]. When a robot uses natural language to communicate to children, the robot raises high expectations of human-like communication in children that are often unattainable [289]. For a robot it is still difficult to parse and understand children's language reliably enough to respond in consequential

ways [195]. As a result, children are often disappointed by the verbal interaction with robots. Increasingly, researchers in HRI are exploring non-verbal ways to communicate in child-robot interaction.

An alternative to using Natural Language in cHRI is the use of **semantic free utterances** (SFUs). SFUs are vocalizations and sounds that have no semantic meaning attached to it [409]. Gibberish speech and non linguistic utterances are the most prevalent SFUs in HRI [409]. Using the terminology of Yilmazyildiz et al. [409], gibberish speech (GS) are vocalizations of meaningless strings of speech sounds that resemble human speech. GS is not quite human language though. GS retains prosodic qualities of human-like vocalizations, but GS does not sound like human-language nor does it have any conventional or iconic meaning. GS has only some paralinguistic features like tone and pitch. Non linguistic utterances (NLUs) are nonvocal re-created sounds that, similar to GS, show no resemblance to natural language, but that unlike GS do not resemble human speech (e.g., beeps, whirrs): an example of NLUs is the language of R2D2, a fictional robot popularized by the Star Wars movies. As such, NLUs are often ambiguous and subject to context.

So far, the application of SFUs (both GS and NLUs) in cHRI is rather limited [409]. Often, SFUs are not applied in real-life, *in-situ* child-robot interaction [290], but only in context-free psychological studies. Most of the studies focus on SFUs as a unimodal communication cue [409], delivered in isolation of other cues. Recent studies have shown the importance of evaluating SFUs in multimodal interaction rather than unimodal, that is to combine the SFU with movements and actions of a robot. However, it is still unclear how SFUs could give clues about the underlying intentions of the robot's movements or actions they are coupled with and what impact the SFUs can have on child-robot interaction.

To tackle the aforementioned challenges, we conducted an exploratory study to evaluate the effects of GS and NLUs in a child-robot collaborative game. We focused on a widely studied prosocial behavior in peer collaboration that is i.e., help-giving [386, 300]. We designed help-giving locomotion of a robothing and coupled it with GS or NLUs or without any sound. Our aim was three-fold: (i) to investigate if SFUs can be accurately recognized by the children in a real-life help-giving context; and (ii) to investigate how two types of SFUs (i.e., GS and NLU) impact the perceived help-giving of robothing behaviors in the game; and (iii) whether the SFUs would have stronger effects on child-robot interactions than robothing locomotion alone.

Drawing on literature, we hypothesized that:

1. **(H1)** SFU sounds will be perceived as being more help-giving than no sound, and in particular, **(H1a)** GS will be perceived as being more help-giving than NLU and no sound, because GS conveys more paralinguistic cues and NLUs can be more prone to ambiguity.

2. **(H2)** The recognition rate of the intention of the sound (help-giving suggestion) for GS will be higher than for NLUs.

In a 1 by 3 (GS vs NLUs vs no sound) between-subjects Wizard of Oz experiment, we found that (i) GS is better recognized than NLUs, (ii) children complied more to the robothing's suggestions in the no sound condition, (iii) children were finishing the game faster in the NLUs condition, but they were playing more independently and less compliant, and (iv) there is no difference in the help-giving perception between GS and NLUs.

4.3.2 *Related Work*

Studies in developmental and evolutionary psychology have shown that non-verbal sounds and vocalizations often accompany actions of humans and great apes to strengthen or disambiguate the action's intention [34, 361, 364]. Non-verbal sounds and vocalizations appear to support the communication of an action or non-conventional gesture even without any semantics, like in natural language [132].

Grunloh et al. [132], have showed that non-verbal vocalizations of children can disambiguate the meaning of a pointing gesture, the gesture being either expressive, requesting or informative depending on their prosodic characteristics. These findings suggest that beyond the contextual information, non-verbal vocalizations are key for non-verbal communication. Not only vocalizations with prosody, but also iconic vocalizations, vocalizations that resemble the referent action or object but are not semantic, communicate in absence of natural language [34].

Non-verbal sounds and vocalizations have been used in HRI, in a similar way as described by studies in children and great apes, to communicate without natural language [409]. Typically in HRI, natural language is the primary modality for human-robot communication. However, researchers are increasingly exploring non-verbal vocalizations and sounds, especially in cHRI. Natural language communication in cHRI faces many shortcomings [27, 409]. The state of the art of natural language generation, understanding and dialogue management stills fall short in cHRI. Understanding children's natural language is difficult, especially during interactions as children do not enunciate or use syntax as adults [195]. Producing language and managing the dialogue with children faces similar challenges. As a result, children are oftentimes disappointed by the verbal interactions with robots and they feel deceived. Moreover, natural language is not universal, posing problems of cross-cultural applicability of child-robot interaction.

One of the first robotic platforms relying on SFUs to communicate is Kismet [39] developed by Breazeal. Kismet used GS to communicate, vocalizations that sound like speech but with no meaning, aligning with gestures and gaze. Kismet's affective meaning was well understood by people thanks to the prosodic qualities of the GS vocalizations. Yilmazyildiz

et al., [409] drew upon Kismet to develop a whole GS language for the robot Probo. In one of their studies, Yilmazyildiz et al. [408] found that a combination of GS and facial expressions would significantly improve the recognition accuracy of affective expressions of Probo.

Another type of SFUs used in HRI are NLUs, sounds not resembling human speech. There are many types of NLUs but the most used are auditory icons [116], sounds that resemble real-world objects or even actions. They are not as arbitrary as language is, but they retain a semantic connection with the object or action they represent, therefore in some instances it might be difficult to understand without knowing the meaning behind the convention. Auditory icons can be distinguished based on their level of arbitrariness. For example, symbolic icons are very arbitrary as they are conventional sounds (e.g., police sirens sound). Metaphoric icons hold similarities with the actions of objects they represent, an example from [409] *“a falling pitch is associated with a reduction in the size or altitude of an object”*. Read et al. have explored non-linguistic utterances in child-robot interaction, particularly to convey affective meaning [289]. An important aspect of NLUs is their relation with the actions or behaviors they accompany. Read et al. [290] have shown that in certain instances the affective interpretation of an action appears to overrule the one of a NLU, but the authors have also shown that NLUs can amplify the interpretation of an action in context. Komatsu et al. explored how NLUs have an effect on the ways a robot is perceived in a task, showing that a robot’s actions paired with NLUs impact the perceptions of how confident the robot acts in a task.

To conclude, SFUs can be used in HRI similarly to how humans and great apes use non-verbal vocalisations and sounds: to amplify and disambiguate the meaning of an action. GS and NLUs are the main types of SFUs used in HRI as an alternative to natural language. GS has prosodic qualities that support the recognition of its meaning, despite not having a semantic. NLUs have less connection to prosody, and are therefore at times more difficult to understand. Both GS and NLUs, when paired with actions of a robot, appear to improve the recognition of the action’s meaning. However, especially NLUs are subject to the context in which they are uttered, influence the perception of a robot, and sometimes are overruled from an action’s meaning.

4.3.3 Methods

We carried out a one by three (GS vs NLUs vs no sound) between-subjects Wizard of Oz experiment. We manipulated only the sounds, the robot movements were equal across conditions. We had one control condition without sounds, only with the movement. Children experienced the robot *in person* and *in situ*. The robot was remotely controlled by a researcher following a predetermined script.

Participants

Eighteen Dutch children ($n = 18$; age: $m = 9.16$, $sd = 0.38$; 8 males, 10 females) in same-gender couples participated in the experiment. Participants were students of grade 6 (8-9 years old) and grade 7 (9-10 years old) of an elementary school in the east of the Netherlands. All the participants were speaking Dutch and knew each other. Participants were randomly selected by the researchers from a list of same gender pupils provided by the teachers of the school. 89% of the participants did not have any prior experiences with robots.

Ethics

The study was approved by the Ethical Committee of the University of Twente (NL). The school principal and teachers were informed about the study and approved of the study to be held at school. Legal caregivers of the children were informed about the scope and methods of the study and gave written consent to the children's participation. Prior to the commencement of the study, children were verbally informed about the study and gave verbal assent. Upon termination of the experiment, the children were fully debriefed about the robothing not being really autonomous, but remotely controlled by a researcher. We deemed the deception concerning the robot's autonomy necessary for experimental purposes.

Game, Robot Behaviors and WoZ

In the experiment participants played a tangible 4 by 4 pair-matching memory game with a robothing. The goal of the game is to match all pairs of identical objects hidden under crates in a sequence of rounds. In each round, two crates can be lifted to see if the objects match. The first rounds usually consist of making guesses — there is no information about the hidden objects yet — but after a few of rounds enough information should be available to make a match, if the objects are remembered.

We designed the help-giving robot behavior movements for a non-anthropomorphic robothing, i.e., Festo Robotino⁵. The robot has omnidirectional wheels which means that the robot can navigate forward but also side-ways: the robot's wheels can perform 3 degree-of-freedom (DOF) motion on a two-dimensional plan (See Figure 22).

Help-giving behaviors consisted of locomotion and sounds (but for the control condition without sounds). To suggest a good game-move, the robot would use its **locomotion** to move towards the crate and nudge the crate hiding an object that could be matched.

In the NLU and GS condition, we paired robot motion of “nudging” with either an **NLU or GS sound** matching the time of the “nudging” movements, i.e., both 2.68 seconds. For the NLUs we used synthesized *metaphoric auditory*

⁵ <http://www.festo-didactic.com/>

icons [409]. For the GS, we inspected prosodic characteristics of children's suggestive speech in a Dutch child-child collaboration corpus (from our observational study in Chapter 3) and tried to replicate those prosodics with a sustained /m/-sound.

The robot was not autonomous, but it was remotely controlled by one of the researchers (the Wizard of Oz [297]) with a joystick. The joystick controlled the motion of the robot and the emission of sound. By tilting the joystick forward or backward the robot would move towards a crate. Once close to the crate the robot would bump into the crate and stop, thereby nudging and giving a helpful suggestion. When bumping, the researcher would press a button for the robot to emit either GS or NLUs depending on the experimental condition.

The locomotion of the robot was programmed as a monotone speed of 3 km/h. Thanks to its omni-wheels, the orientation of the locomotion remained the same no matter where the robot was in the playground. In other words, the robot did not need an extra behavior to rotate itself and re-position itself to move forward towards a crate to give game suggestions. No matter the robot position in the playground, the omni-wheel system would guarantee that the robot would exhibit only the designed behavior, i.e., towards locomotion colliding with a crate to “nudge it”.

The robot assisted to find pairs of objects in the game. Therefore it would not intervene at all times. The knowledge of the robot was always equal to maximum possible knowledge of the children. The robot gave help by providing **game move suggestions** when the possibility of matching a pair of objects was possible from the knowledge of the game, but otherwise it would follow and watch the children making guesses, not interfering.

Setup and Procedure

To guarantee higher ecological validity, the experiment took place in the gym room of the participants' school. The gym room was a familiar “play-room” to the participants. In the room, we set up 16 crates in a 4 by 4 matrix (See Figure 22). Underneath the crates, we hid everyday objects to be matched in the pair game. We kept the position of the objects underneath the crates constant for each experimental session. The room was equipped with a camera for video recordings, placed lateral to the 4x4 matrix of crates to capture the full interaction in the game. The Wizard of Oz researcher sat in the same room but hidden from the children, whom could not see the researcher while playing.

Dyads of participants were accompanied to the gym by a teacher and then welcomed by a researcher. After explaining the goal of the game and of the experiment, participants would familiarize with the robothing for three minutes. The researcher would then ask verbal assent to participate in the experiment. Once the assent was granted, the researcher would start the recording and the game. After a couple of rounds the robothing would

start with the help-giving behaviors. The game would end when all the objects were matched by the participants. The researcher was instructed to stop at 20 minutes regardless of the state of the game. After the game, participants were asked to individually reply to a visual item that illustrated the different possible SFUs, to validate the SFUs (i.e., ex-post recognition test). Participants were then debriefed and accompanied back to the class.

Measures and Data analysis

To evaluate the children's recognition of SFUs intention, we carried out an *ex-post* recognition test in the GS and NLU conditions. The participants had to match the sounds — replayed by the robot at this time — to four cartoon-like images depicting the intentions of the sounds (i.e., suggestion, doubt, error, reward, see Figure 23). Following recommendations for testing with children [243], we chose cartoon-like images to facilitate children's association between the SFUs and intention, and we explained the meaning of the images to the children prior to recognition test. Participants were asked “What cartoon-like image suits best the sound the robot did in the game? Here's a replay of the sound” pointed to the cartoon-like image after the robot would reply the SFUs.

To evaluate the effect of our manipulation on the perceived help-giving of the robot behaviors in the game, we used observational methods. Two coders (inter-rater agreement 0.896) observed **compliance to suggestion rate** (i.e., number of times complied to help-giving suggestions divided by total number of help-giving suggestions) and **average game-round duration** (i.e., total game duration divided by number of rounds in the game). The rationale behind these measures is to have an objective overview of the children's perception of the help-giving roboting behavior in a collaborative game context. We operationalized the robot to be perceived as help-giving when there is: high compliance to help-giving suggestions, which should result in a low average round game duration. We think that if there is perceived help-giving, compliance will be high, the children will be decisive and therefore the rounds will be short. Consequently, if there is no or less perceived help-giving, the compliance will be low, the children are more indecisive, and the game rounds will take more time. On average participants took 5 minutes to complete the game, and the longest session was of 8 minutes and 26 seconds.

4.3.4 Results

SFUs Recognition Rate (H2)

The recognition of the help-giving sounds was higher in the GS condition (85%) than in the NLU condition (20%). Participants recognized the GS as being suggestive more than in the NLU condition. The result falls within

Figure 22: A screenshot from the data collected. In the picture, two participants playing with the robot the tangible 4x4 pair-matching memory game.

Figure 23: The figure shows in a) one of the participants compiling responding to our ex-post recognition test. Figure b) shows the four cartoon-like images depicting the intentions of the sounds (i.e., suggestion, doubt, error, reward).

our expectations (H2: The recognition rate of the intention of the sound for GS will be higher than for NLU).

Perception of help-giving in the game (H1)

A three-way ANOVA with post-hoc Bonferroni correction showed that the participants took on average less time each round ($F(2, 15) = 4.202$, $p = .036$) in the NLU ($m = 17.76$, $sd = 3.41$) compared to the NS ($m = 28.36$, $sd = 10.62$) condition, but no differences between GS ($m = 19.92$, $sd = 3.16$)

and NLU or NS were found (See Figure 25). The same trend emerged for the rate of compliance ($F(2, 15) = 8.152, p = .004$), where the rate was lower in NLU ($m = 0.69, sd = 0.02$) than in NS ($m = 0.90, sd = 0.22$), and again no differences between GS ($m = 0.78, sd = 0.20$) and NLU or NS were found (See Figure 24).

The results only partially support our hypothesis (H1) that SFUs sound will be perceived as being more help-giving than the control condition (NS). Participants were faster in the NLU and GS conditions, but –surprisingly– complied significantly more with the suggestions in the NS. Contrary to our expectations, our H1a hypothesis is not supported by the results. We expected GS to be perceived as more help-giving than NLU, but we have found no significant differences.

Additional Qualitative Analysis

To explain our quantitative results, we have carried out some additional qualitative observations of the video recordings. Our goal was to find indications that would explain *why* the children had a higher rate of compliance, but were slower in finishing the rounds in the NS condition compared to the NLU and GS conditions. We observed that the participants in NS await the robothing's turn for suggestions, to jointly act with the robothing. Conversely, participants seemed more assertive and independent in the game in the NLU condition, which can be substantiated by the slower game time. Similarly to the NS condition, in the GS condition children showed more joint-actions with the robothing, which was lacking in the NLU condition where the participants played the game independently from the robothing's help-giving.

4.3.5 *Discussion*

Our findings provide insights on (i) the recognition of help-giving SFUs in a game context, (ii) how the interpretation of SFUs affects perceived help-giving of the robothing in the game, and (iii) the viability of SFUs to communicate a robothing's intention in child-robot interaction in collaborative play.

(i) As expected (H2), the children were able to match the GS to its intention with a better recognition rate than the NLU. We assume that the stronger paralinguistic cues carried by the GS helped the children in the recognition [293]. Additionally, the results of the recognition of the NLUs show that they lead to more ambiguity in the interpretation of the intention. This is partly in line with the literature on NLUs [289]. The NLUs examined in this experiment were metaphoric auditory icons, as such the examined NLUs were holding strong similarities with the action they represent, in this case a nudge, but they are still somewhat iconic, therefore they need to be

Figure 24: The graph shows the results of the rate of compliance per round. Compliance was significantly higher in the NS condition than in the NS and GS condition ($F(2, 15) = 8.152, p = .004$). Error bars show the 95% confidence interval.

Figure 25: The graph shows the results of the average time per round. Rounds were significantly quicker in the NS condition than in the NS ($F(2, 15) = 4.202, p = .036$), but no difference were found between NS and GS. Error bars show the 95% confidence interval.

interpreted [116].

(ii) We hypothesized SFU sounds would be perceived as being more help-giving than no sound, and operationalized that being more help-giving would result in a high compliance to suggestion rate and therefore a fast round time. However, for NS, we observed a significantly *higher* compliance rate and *slower* round time compared to NLU. We think that NLU behavior

caused more indifference to robot suggestions as the NLU sound part was not well recognizable. But, we expected that a lower compliance rate for NLU would result in *slower*, not faster round time. We expected SFU sounds to be perceived as more help-giving than no sounds (H1), specifically for GS (H1a), but this was not the case. Our additional qualitative findings, may suggest our NLUs might be too confusing for the children, leading them to play independently from the robothing's suggestions, which may have affected their round times. GS leads to similar observations, but children seem to engage in more joint actions with the robothing as children might have a better understanding of the underlying intention of the robothing, as shown from the recognition rate results.

(iii) Interestingly, without the SFUs, the intentions of the robothing actions were clear to the children, as the high compliance in the control condition (NS, no sound) shows. Additionally, qualitative observations may suggest that children were engaging more in joint actions when the robothing did not emit any sounds. We can infer that the actions by themselves were clear to the children, but when combined with the NLU and to certain extent when combined with GS, they were misleading to the children. This is in line with the literature [361, 240] covered in our framework for designing robothings (See, Chapter 2): an agent's actions (in our case the robothing's actions) clearly convey its underlining intention if the context is clear and the agent actions are designed to clearly show goal directness [361]. In other words, the locomotion ending with the nudge to the crate sufficiently indicates the underlying help-giving intention to children in the game, who complied with the robothing and played along with the robothing. However, our results appear to not corroborate that non-verbal sounds and vocalizations accompanying actions strengthen or disambiguate actions' meaning for robothings as much as it happens in humans [34, 132]. Clearly, more extensive studies are needed to shed light on the role SFUs could play in HRI.

Our results have design implications. SFUs may not be directly necessary to provide extra information or to provide extra cues about the intention of a robothing to children. Actions and motion alone, if designed to communicate in "human terms" could be sufficient for child-robot interaction. GS might be more adequate for child-robot interaction as the paralinguistic features could better support communication to children. NLUs should be carefully designed to make sure the underlining meaning is transparent. In general, more research is needed to understand whether SFUs are viable in HRI. Indirectly, on a methodological level, similar to [409], we provide indications that evaluating SFUs in context during in-person experiments is key to appreciate the viability of SFUs in HRI. Our recognition results alone were not able to capture how SFUs were really perceived by children in the interaction. While our observation results provide us with a clearer picture of how SFUs were perceived and how the perception of SFUs impacted the results.

Limitations

Our exploratory study has some limitations. First, we are aware our sample size was too small to have a comprehensive picture of the phenomenon. Arranging studies with the children population poses more hurdles than with adults, as a result many of the cHRI studies have sample sizes below 30 participants. We leave a study with a bigger sample to future work. Similarly, we tested only with children from the Netherlands raised in the so-called western culture. A more diverse sample could yield different results as, especially NLUs, can have cultural connotations [116].

Second, by focusing only on a subset of SFUs and on two particular instances of GS and NLUs, our results do not apply to the complete spectrum of SFUs (for a review of the field see [409]. More research is needed to better understand the SFUs effects in HRI and cHRI.

Third, as per our scope, we have only tested the SFUs coupled with the robothing motion to provide a suggestion in the game. The SFUs de-coupled from the robothing locomotion could have yielded different results. The robothing's actions by virtue of being designed to readily communicate the intention might have been "louder" than the sounds.

Finally, for our exploratory study we chose to measure the perception of help-giving through behavior observations as opposed to subjective report (i.e., survey). The rationale behind the measurement choice is that children experience difficulties in responding to surveys, especially to report their perception of an experience [243] and often behavioral measures are preferred with children [284, 127]. Mindful of the difficulty for children to reply to surveys, in our ex-post recognition test we used cartoon-like icons to scaffold the children's understanding of the questions.

4.3.6 *Conclusions Study 3*

In this exploratory experiment, we have investigated how sound in the form of semantic free utterances (gibberish speech and non-linguistic utterances) could support the communication of help-giving in child-robot interaction. We show that gibberish speech is recognized better than non-linguistic utterances, but contrary to our expectations we show that children play a game faster and comply to more robothing suggestions, when the robothing was exhibiting only motion.

Our exploratory results suggest that motion alone can be "louder" than sound when trying to communicate help-giving intentions during child-robot collaborative play. While in human pre-verbal communication, SFUs support the communication of the intention of an action, we do not observe the same in our study. On a methodological level, our findings suggest that when designing help-giving SFU robot behaviors for cHRI, it is important to not only investigate the recognition of the behaviors, but also how the recognition of the behaviors will affect the child-robot interaction.

Our study contributes to HRI and cHRI with initial indications that actions designed to communicate in “human terms” according to our framework are sufficient to achieve clear communication and positive collaborative play performance in cHRI. Adding sounds to a robothing’s motion does not reinforce the child-robot communication. On the contrary, we show instances of hindering child-robot interaction. Following the results of this study, we decided to not pursue SFUs as a viable modality to achieve child-robot communication in collaborative play.

4.4 STUDY 4: EXPLORING A ROBOTHING'S INFLUENCE ON CHILDREN'S RECIPROCITY

This section presents a longitudinal case-study that explores the influence of robothing's behaviors on children's reciprocity. The case-study builds upon the results of Study 2 and Study 3. Legible communication of a robothing is a prerequisite for the robothing to influence children's collaborative dynamics and promote prosocial behaviors in collaborative play (see Chapter 2). Both Study 2 and Study 3 have provided indications that a robothing's minimal gaze-movements (Study 2) and a robothing's motion (Study 3) can legibly communicate to children, influencing their perception of a robothing. Now to further test the framework of this dissertation, we need to discern whether and how the robothing's behaviors will have an effect on children's collaboration and prosocial behaviors.

So far, we have empirically evaluated our robothing's behavior prototypes with children in VHRI (Study 2) and HRI studies (Study 3). In this study, we opt for a more qualitative approach, focusing only on one cohort of children, to gain a deep understanding of how a robothing influences children's reciprocity towards the robot and other children.

We discuss findings regarding the effects of the robothing's behavior on children's reciprocity, children's explanation of their motivations to help in the game and children's tendency to help the robot after the game. Our findings have implications for our framework: We provide preliminary indications that robothing's behaviors promote prosocial behaviors (i.e., reciprocity) and have an impact on the way children collaborate with each other. At the same time, we provide indications that children explain a robothing's and their own behavior in unexpected ways. We have observed discrepancies between children's behavioral reactions in the game and their explanations of both their own and the robothing's behavior. We conclude with suggesting that exploring these discrepancies early in the design process could be beneficial to avoid misalignment between what children think about the interaction and what designers would like to achieve with a robothing intervention.

4.4.1 *Introduction*

When somebody shares objects or information with us to help us, we are compelled to reciprocate this act and we perceive the person as being prosocial and likeable. Indirectly, we are compelled to start sharing or helping others too, even if we are not the direct recipient of the sharing or helping act [267]. Reciprocal dynamics are very important to regulate the way we collaborate with one another and they depend on the acts of the people we are collaborating with both in the present and in the past. The reputation of a person to be helpful and sharing is also important: past interactions influence our tendency to collaborate and reciprocate [265, 264].

Children are very sensitive to reciprocal dynamics, especially reciprocal actions, and they pick-up prosocial actions (i.e., sharing, helping) from each other (we have shown this in Chapter 2 and Chapter 3). Children tend to reciprocate a child who is prosocial to them or children whom they observed helping a third party or each other [391, 389, 283]. Children will judge it fair to share with a child that shared in the past or that helped and co-operated, but children might sanction a child that stops sharing or helping [97]. These reciprocal dynamics support the development of children's prosocial behaviors and the ability to regulate prosocial behavior in interactions such as collaborative play [266]. In a nutshell, interacting with somebody who shares and helps compels children to have social motivation to reciprocate and contribute to the regulation of collaboration.

Would a robot sort a similar effect? How would a robot that shares objects in playful tasks influence children's reciprocal dynamics? How would children respond to a robot with a helpful reputation that stops sharing? The literature of cHRI regarding prosocial behaviors and reciprocity is scarce: there are only early indications about children helping a robot in need and some indications of prosocial dynamics with adults, but scholars have not yet explored these ideas in HRI and cHRI.

We present a case-study that addresses the aforementioned questions and gaps. This dissertation focuses on designing robothings that regulate children's collaborative behavior and promotes children's prosocial behavior through play. Reciprocity is one of the main collaborative dynamics that promotes prosocial behaviors in children. Therefore, we sought to understand: (i) how a robothing's sharing behavior influences children's direct reciprocity to the robot, and indirectly to the other children, and (ii) if previous sharing interactions with the robot have an effect on children's reciprocal interaction when the robot stops to share. With these goals in mind, we formulated the following sub-question to our RQ5: *What are the effects of a robothing's behavior on children's collaboration and prosocial behaviors?* (See Chapter 1):

- **Sub-question 1** How does interacting multiple times with a robothing that shares objects influence a) children's direct reciprocity towards the robot, b) children's indirect reciprocity towards each other and c) children's motivation to help the robothing and the other children?

We expected that playing with a robot exhibiting sharing behaviors will influence children to reciprocate prosocial behaviors: both directly and indirectly. Conversely, we expected that when the robot will stop sharing: children will sanction the robot's behavior and stop to share with the robot. In this case, children might try to re-engage with the robot to behave in the normative way (i.e., being prosocial and sharing between each other).

We carried out a longitudinal (4 sessions in 3 months) case-study with a cohort of children ($n = 3$). The case-study consists of four consecutive sessions wherein this small-group of children and a robothing are engaged in a playful sorting game (based on interaction scenarios developed in Chapter

3). After a baseline session, the robothing shares relevant resources with the children in the task for two consecutive sessions. In the fourth session, the robot does not share anymore, but takes away relevant resources from the task.

Our findings show that the robot's prosocial behavior has an influence on direct reciprocity towards the robot and indirect reciprocity towards the other children. When the robot exhibited sharing behavior children reciprocate directly and indirectly in the game. Children were helping the robot also after the game. When the robot stopped sharing and took away relevant resources from the game, children retained the effects on indirect reciprocity, i.e., they were sharing with each other in the task, but they were not sharing with the robot anymore during and after the game. Furthermore, children appear to be able to describe the motivation of their behaviors as due to feelings of empathy towards the robot or because of enforcement of the norm of cooperation in the group. This finding may suggest that the robot behavior had some influence on children's cooperative norms of the group and that further empirical investigations in this direction are needed. Based on these findings and on additional observations, we discuss design and methodological implications.

The longitudinal case-study makes **three contributions**: first, we provide preliminary indications that being exposed to a robot communicating only with non-verbal sharing actions influences children's reciprocal dynamics. The findings open-up opportunities to further investigate how robothing interventions could promote collaborative and prosocial behavior through collaborative play. Second, the longitudinal case-study provides insightful recommendations for design. Third, we introduce a semi in the wild study protocol to study children-robot interactions in playful tasks.

4.4.2 *Background and Related Work*

We have seen in Chapter 2 that prosocial behaviors are behaviors oriented to others, such as sharing, helping, cooperating and comforting [91, 97]. In our research, we are mainly interested in prosocial behaviors (i.e., sharing resources to help another to reach a goal in the task) that occur within the context of collaborative play at the interpersonal level (i.e., one person needs assistance and the other possesses the resources necessary to provide) [91].

Whilst children have a natural tendency to be prosocial, they become more selective as they grow up and interact in the social world [100]. Children pick-up from other children when and how to behave to collaborate and be prosocial with one another. Reciprocity, both direct and indirect, mediates much of helping and sharing and supports the establishment of prosocial norms. Interacting with peers who share and help promotes the development of dynamics, norms and beliefs that are important for collaboration. At the same time children assess whether to reciprocate or be prosocial with another depending on their present and past behaviors. For

Figure 26: Figure taken from [264] to illustrate direct and indirect reciprocity. Top shows direct reciprocity. Bottom shows indirect reciprocity, divided into upstream (left) and downstream (right).

example, children prefer prosocial individuals over antisocial individuals and tend to sanction antisocial behaviors by not reciprocating or collaborating with antisocial individuals [396]. Interacting with prosocial peers promotes the development of norms and beliefs about prosocial behaviors that consequently guides children's prosocial behaviors with others in the long term. For example, Fabes and colleagues [100] found that exposure to prosocial peers was related to increased prosocial behavior a year later.

It appears evident that children tend to reciprocate a child who is prosocial to them or children whom they observed helping a third party or each other. These reciprocal dynamics support the development of children's prosocial behaviors and the ability to regulate prosocial behavior in interactions.

There are different ways to be reciprocal with one another. Reciprocal dynamics can be direct and indirect.

Direct reciprocity (See Figure 26a, the top Figure) is based on one or more interactions between two children. It can be defined as '*reciprocating the prosocial behavior I have received from you*' [264]. Being the recipient of a prosocial behavior such as sharing supports the emergence of direct reciprocity (i.e., anyone who receives a prosocial behavior is likely to reciprocate and consider the "giver" as a helpful person worthy to be reciprocated).

Indirect reciprocity (Fig. 26b, bottom Figure) is based on observing prosocial interactions. It can be defined as '*I help/share with you because of the help/sharing you have given to others in the task and previous encounters*' [264]. We distinguish between *upstream indirect reciprocity* (i.e., if the recipient of a prosocial behavior reciprocates another child who was not sharing or helping him before) and *downstream reciprocity* (i.e., the child who exhibited prosocial behavior towards another participant becomes the recipient of a prosocial behavior). Indirect reciprocity is more likely to develop overtime and it is likely the byproduct of the perception of the robot or other participants as prosocial (i.e., helpful, cooperative).

Figure 27: The figure illustrates the case-study sessions.

Reciprocity and prosocial interactions have mainly been studied in HRI with adults, with little to no studies in cHRI. There are some indications that a prosocial or antisocial behavior of a robot might influence people's tendency to reciprocate and positively perceive a robot. Correia et al. [62] showed that a robot that behaves prosocially in a team is endowed with more positive social qualities than a selfish robot. Sandoval et al. [304] unveiled that a robot that bribes humans receives significantly less reciprocation than a robot that does not bribe. Jung et al. [184] showed that a robot sharing resources impacts and shapes team dynamics. However, little is known in cHRI. To date, only Beran [28] has studied children's tendency to help a robot in need showing that children are most likely to help a robot after experiencing a positive introduction, but there are (to the best of our knowledge) no studies that investigate how a robot influences children's reciprocal dynamics.

To conclude, direct and indirect reciprocity are important dynamics to regulate collaboration and promote prosocial behavior in childhood. Children tend to reciprocate those who are prosocial to them and tend to be more inclined to interact with peers and adults who have a prosocial reputation. While HRI studies have showed similar dynamics between humans and robots, little is known about child-robot interaction and reciprocity.

4.4.3 Methods

We carried out an **exploratory longitudinal single case-study** [410] with a cohort of three children. The case study consists of four consecutive sessions in one or two weeks interval. It was conducted from November 2017 to January 2018. During each session, children engaged in a playful sorting game (i.e., sorting objects for an imaginary adventure on the planet Mars) together with a low-anthropomorphic robothing, the Squirrel robot. After a baseline session, the robot shares relevant resources for the sorting game when a child is in need of objects while playing the game. After two sessions, the robot stops sharing and takes relevant resources away from the game (see Figure 27).

Participant	Gender	Age	Experience with robots
C1	M	9	yes
C2	F	8	yes
C3	M	7	yes

Table 11: The cohort demographics and prior experience with robots. C1, C2, C3 are abbreviations that indicate the three participants (child 1, 2, 3).

Participants

Participants were randomly selected from a mixed gender pool of children attending an after-school program in Vienna, Austria. Three children ($n = 3$, two boys and one girl, mean age = 8 years; $sd = 1$) from a medium-high socio-economical background are part of the cohort. All the children are attending public elementary schools (not the same school) in Vienna and can read and write reasonably well for their age. The cohort was already familiar with the Squirrel Robot and with robots in general. However, participants never played in a game with a robot before.

The participants in the cohort know each other, as they are part of the same after-school program. According to the care givers though, the participants are not in a particular friendship relationship (e.g., not best friend or exclusive play mates), nor have they exhibited episodes of peer rejection amongst each other in the past.

We asked caregivers to provide an assessment of the participants socio-emotional behavior. The goal of this assessment is to establish a socio-emotional profile of the cohort, which is useful to understand whether the cohort's behavior during the interaction sessions with the robothing will deviate from usual or not. To this end, we administered a German version of the **Strength and Difficulty Questionnaire (SDQ)** [202], the (SDQ-Deu) to the cohort's teachers. The SDQ-Deu questionnaire asks about 25 attributes of the children, some positive and others negative. Main constructs covered in the questionnaires are: emotional behaviors (5 items), conduct problems (5 items), hyperactivity/inattention (5 items), peer relationship (5 items), and prosocial behavior (5 items). For each item, teachers were asked to mark a box for Not True, Somewhat True or Certainly True (See Appendix A.1, Section A.1.1 for the full set of items as presented to the teachers). Teachers were asked to give answers on the basis of the child's behavior over the last six months or this school year. The SDQ scores for each construct are compared against the general population and can result in low, high, slightly high or average scores. Results are summarized in Table 12: all the children score average in all the traits, also in comparison to the normal scores in a population of German speaking children, except one of the participants (C1) who scores slightly higher in the hyperactivity score.

After the first session (i.e., baseline), participants answered a **Pictorial Big Five Scale (PPTQ)** [238] questionnaire, a new validated instrument

Score	Low	Average	Slightly high	High
Prosocial		C ₁ , C ₂ , C ₃		
Emotional problems		C ₁ , C ₂ , C ₃		
Conduct problems		C ₁ , C ₂ , C ₃		
Hyperactivity		C ₂ , C ₃	C ₁	
Peer problems		C ₁ , C ₂ , C ₃		

Table 12: Results from the SDQ-Deu questionnaires. The SDQ scores for each construct are compared against the general population and can result in high, slightly high, average, or low scores. We show the score of each participant by placing the participant's abbreviation in the corresponding cell.

I usually play...

on my own it depends with others

When I usually go to school...

I'm worried it depends I'm calm

I usually do my housework...

willingly definitely yes a little bit it depends a little bit definitely yes unwillingly

When I'm able to help somebody...

I help definitely yes a little bit it depends a little bit definitely yes I don't help

Figure 28: A sample of questions from the personality test developed by [238] as administrated to the children

for measuring personality traits, particularly in a group of young children (aged 7-10 years). Although we are not interested in children's personality directly, results about children's personality traits can serve as a robust profile of children's socio-emotional behaviors and behavioral tendencies. In each questionnaire item, the same character (See Appendix A.1 for the full questionnaire in German) is presented in various scenarios. The participant chooses the picture in which the main character behaves as he or she would in the situation and indicates his or her similarity to the main character on 5-point response scale. Figure 28 shows a sample of the translated questionnaire. Figure 29 provides the results of the personality test. The results indicate that Child 1 and Child 3 score relatively high or very high in agreeableness (arguably a trait that indicates prosociality) while Child 2 has a medium score. Child 1 scores low in neuroticism (i.e., arguably more emotional stability) and conscientiousness in to respect of the other participants. Child 2 has the higher score in extraversion.

Figure 29: Results personality traits for C1, C2,C3, the children in the cohort

Robothing, Robothing Behaviors, WoZ and Game

The Squirrel robot (See Figure 30 and 31) was the robothing platform for the case-study. The Squirrel Robot is a low-anthropomorphic research platform designed by the EU Squirrel Project consortium⁶. The Squirrel Robot can be considered a robothing as it is an hybrid between an appliance (i.e., cleaner) and a social robot that tidies-up objects with children. The Squirrel robot communicated only non-verbally through locomotion and gesture: it has one anthropomorphic cue, one non-actuated digital eye (on a screen) and a robotic arm tucked beneath its belly. For the purpose of this study, we did not use the arm. The Squirrel robot was named Kenny by the children thus we kept this name during the case study.

⁶ <http://www.squirrel-project.eu/>

Figure 30: In the figure a rendering of the Squirrel Robot, the robothing we examined in this case-study.

Figure 31: In the figure a visual representation of the robothing's behaviors in the case-study. On the left the social gaze-movements (as designed in Study 2). On the right the sharing behavior and taking away behaviors: The robothing "pushed" by driving (locomotion) a relevant object either in the direction of one of the children (to share the object) or away from the children (to take away the object). To participate in the game the robot used a similar behavior to push the object in the "dispatch area" in the center.

The resulting robothing behaviors were as follows:

- Social-gaze movements: We implemented the social gaze-movements (From Study 1) to disambiguate who the robothing was addressing prior to sharing an object. The social gaze-movements lasted for 5 seconds;
- Sharing behavior: We implemented a sharing behavior the robothing exhibited after the social-gaze movements during the second and third session of the case study. The robothing showed a sharing behavior 3 times during the two sessions. The robothing used its locomotion to move a relevant object towards one of the children. By driving against an object the robothing “pushed” it towards the child stopping right in front of the sorting area of the child, thereby sharing the object with the child. After stopping, the robothing drives back to its sorting area. The robot drove monotonously at 3 km an hour;
- Taking behavior: We implemented a taking behavior the robothing exhibited after the social-gaze movements during the fourth and last session of the case study. The robothing showed a taking behavior 3 times during the session. The robothing used its locomotion to move a relevant object away from the children, outside of the playground. The behavior is exactly the same as the sharing behavior, but for the recipient of the object;
- Playing behavior: The robot played in the game by pushing the object it needed to sort. The behavior is the same as the sharing and taking behavior, but the robothing drives towards the centred of the room to the “the dispatch area”.

The robothing was remotely controlled using the **Wizard of Oz** approach. The robot locomotion and rotation of the base were remotely controlled via a joystick. Velocity and acceleration were pre-programmed in the robot to remain constant. A researcher was responsible for the WoZ. The researcher sat in another room just outside the case-study room, observing the room via an action camera placed on the ceiling connected through Bluetooth with a tablet. The researcher was instructed to wait for the robot's turn to start remotely controlling the robot following the provided script: the first 2 rounds of robothing were playing behaviors. The following 3 rounds were sharing behaviors or taking behaviors depending on the session. The conclusive rounds were playing behaviors. The WoZ researcher was instructed to stop the robot as soon as the robot was out of objects in its sorting area. Additionally, the researcher was instructed to halt the robot if the children would touch the robot when in motion, or if they would interfere with its behavior, or if the children would leave the room.

Based upon our scenarios (See Chapter 3), we designed a **sorting game** with rules and a back story. We designed a Mars expedition game that

Figure 32: The figure is a screenshot from the recordings. The figure describes the setup of the case-study.

consisted of 4 episodes. We did not enforce collaboration or sharing through game mechanics, but we designed the game with sharing and cooperative opportunities. The main back story was as follows: *“You find yourself on the planet Mars with other children and Kenny, a robot. In order to go back to your spaceship, you need to solve a sorting mission.”* Every sorting mission consisted of the same sorting game, but with different objects. Children were assigned an area full with assorted objects. Each child and the robot had a mission to retrieve a specific type of object from this area (every child and the robot were assigned a different object to retrieve) and bringing it in the assigned area called “the dispatch area” so that the object would be available for the spaceship to function. For each session, we selected convenience items like food boxes, Lego, various toys. Once all the children retrieved all the objects assigned to them, the mission is complete and the children can escape the planet by gathering next to the space station. We made sure that in each sorting area, both the children and the robot had objects the other players would need to retrieve all the objects assigned. In doing so, we created opportunity for the children to share objects with others.

4.4.4 Setup and Procedure

The case-study took place in two rooms in the Technical University of Vienna. One case-study room and one WoZ (Wizard of OZ)/interview room. The case-study room was decorated with scenario props to create the illusion of being in a “Mars Expedition”.

The case-study room (Figure 32) was divided in four sorting areas, assigned to each participant and the robot at the beginning of every session. To avoid learnability and confound effects, the participant's position (robot included) was changed during every session. The center of the room, i.e., the dispatch center was marked to signal where objects needed to be sorted. The space station area, where participants were invited to gather when the game was finished, was in a corner next to the exit door. A display was placed at one side of the room (visible to all the participants) connected to a laptop. The display signaled participants' turn by showing the participant's name (robot included) on the screen. We developed a simple randomized program, that automatically changed the name at fixed intervals (60 seconds). Four cameras were placed in the corners of the room to video-record the interactions. One Bluetooth action camera was placed on one side of the room to capture the room from above for the WoZ remote control. The action camera's live feed was connected to a tablet device.

The interview room was used as a WoZ station and for the ex-post interviews. The room was equipped with a laptop, a tablet, a camera, a voice recorder and the materials for the interviews.

Five researchers administered the sessions: a session facilitator, an interviewer, one researcher remotely controlling the robot, and two observers. A pedagogue from the after-school program was present (but not during the session with the robot).

The procedure was as follows: The sessions' facilitator welcomed the participants and facilitated the familiarization with the robot, the setting and the other researchers on site. The facilitator sat with the participants and explained the task for the session. After the explanation, the session started and the facilitator left the room, thereby leaving participants alone. The researchers were instructed not to be in the room and to enter only after the task was finished or in case of problems. If the participants would leave the room seeking for help from adults, the facilitator was instructed to assist, but to not give any precise information if inquired by the children about the robot's behavior. Researchers and caregivers could check the situation in the interview room via action camera feed on the tablet.

4.4.5 Measures

As is customary in case-study research [410], we relied on multiple data sources. Participants' behavioral observations (the most reliable method in cHRI [225]), ex-post forced choice behavioral measures (widely used in developmental psychology see for example [283]), developmentally appropriate [242] semi-structured interviews.

We conducted behavior observations of **direct reciprocity** and **indirect reciprocity**. To investigate whether the sharing or taking behavior would carry-on its effect after the game, we developed a forced choice "**help test**". Additionally, we inquired the children about their **motivation to**

		Measures
Direct Reciprocity (D)	Observation	Coded D when Robot helps Child(ren) and Child(ren) helps Robot back
Help-test	Observation	Coded Yes if child help Robot Coded No if child does not help robot
Indirect Reciprocity (IR)	Observation	Coded IR Upstream when Robot helps one of the Child(dren) and one of the other Child(ren) helps Robot Coded IR downstream when Robot helps one of the Child(ren) and that Child(ren) helps other Child
Understanding of robothing behavior	Interview	Structured items 1. What did you do during the game? 2. What was the robot doing in the game? 3. Can you describe what the robot did? 4. What did the robot try to do when he did this? Show Picture.
Motivation to help	Interview	1. Did you help the robot in the task? 2. Did you help the other children in the task? 3. How did you help the robot? 4. How did you help the children? 5. Why did you help the robot? 6. Why did you help the other children? 7. Why do you think the robot this this? Show picture of behavior.

Table 13: The table summarizes the measures of the case-studies and how they were measured in terms of interview items or behavior annotation from observations.

help, i.e., their motivation to share in the task and their understanding of robothing's behavior (in terms of legibility and intention of the robot) in ex-post structured interviews.

Direct reciprocity

We observed and annotated the direct reciprocity behavior during the game. Two annotators watched the video recording and annotated occurrences of direct reciprocity after a robot's sharing or taking behavior. We based our definition of reciprocal behavior for our coding scheme on developmental psychology literature [192, 391]. The two annotators had nearly perfect agreement.

Indirect reciprocity

In a similar way as for direct reciprocity, two annotators watched the video recordings and annotated indirect reciprocity as follows: we observed the frequency of indirect reciprocity behaviors in the task (i.e., counting occurrences of indirect reciprocal behavior) and the direction of the reciprocal behaviors (i.e., towards whom the child was reciprocating) for each session. For the latter we distinguish between upstream indirect reciprocity (i.e., if the recipient of a sharing behavior share with another child) and downstream reciprocity (i.e., the participant who exhibited prosocial behavior towards another participant becomes the recipient of a prosocial behavior). Our definitions are derived from developmental psychology literature [117, 265, 192], see Table 13. The two annotators had nearly perfect agreement.

Tendency to help

To understand whether the children would help the robothing after the game we devised a forced-choice help-test. The help test is inspired by established measures in developmental psychology [283] to measure the natural disposition to help and it is modeled on Warneken's and Tomasello's out-of reach-task, i.e., a situation in which a confederate appeared to be unable to reach a goal. We created a series of situations (see Table 14) in which the robothing needed help from the children and we observed if the children helped the robothing or not. In the baseline, the help-test aims to assess the natural tendency to help the robot even without manipulation. In the subsequent sessions, the help-test aims to assess the tendency to help the robothing after being exposed to the robot's behaviors. This is important to test because children can be naturally compelled to help in instrumental situations [389], but their helping tendencies are often mediated by how the person in need of help has behaved before. We devised a different kind of test for every session to avoid the potential learnability effects. The two annotators had nearly perfect agreement.

Help Test	Description	Code
Baseline	R cannot move forward because a lot of objects are in its way	Yes: C moves to R and move away objects; No: C does not move away objects
Sharing 1	R is stuck in an angle and it cannot reach an object	Yes: C moves the object in a better trajectory for R; No: C does move the object for R
Sharing 2	There is a block stuck under R wheels	Yes: C free the object from R's wheels; No: C does not free the object from R's wheels
Taking 3	R is losing battery fast. It needs to reach charging, but can't station	Yes: C helps R reaching charging station or the cord; No: C does not help R reaching the station or cord

Table 14: The table provide a detailed description of the four forced choice help tests devised to measure tendency to help the robothing after the game. Abbreviations in the table are as follows: R stands for robothings, C stands for child.

Motivation to help

To gain a deeper understanding of children's motivation to reciprocate/help the robot and other children, we asked questions about their motivation to help in the task. In our sessions, we evaluated children's motivation to help the robot behavior and the other children via semi-structured interviews. We adapted the questions from the motivation to help scale [392], a validated instrument. We administered the questions ex-post interaction. We analyzed emerging themes from children's answers, providing relevant quotes. We report the analysis of the answers per session.

Children's Understanding of the Robothing Behavior

Two researchers independently annotated the items relating to understanding the robothing behavior following an annotation scheme. Researchers evaluated the presence of words and sentences in the participants' answers that describe participants' understanding of the robot behavior and the situation. The coders coded according to themes corresponding to descriptions, see Table 15. Coders reached good agreement.

4.4.6 *Findings*

In this section, we report findings per measure per session (Baseline, Sharing 1, Sharing 2, Taking 3) and per participant (child 1 - C1, child 2 - C2, child 3 - C3).

Coded Themes	Operational definition
Sharing Behavior	Helping in the task, sharing objects, giving objects, fetching objects, bringing objects
Prosocial Motive	An act of helping a co-player in need of objects. It could be described as bringing an object, pushing, giving, fetching to share or help.
Taking Behavior	Not helping in the task, not sharing objects, not giving objects, taking away an object, not fetching objects, not bringing objects
Antisocial Motive	An Hindering act towards co-player in need of object, not helpful, not sharing, not giving
Alternative Explanation	Any alternative description of robot behavior that does not fall in the others
Playing Behavior	Bringing objects around the room, sorting objects, pushing objects, moving objects, playing with objects
Playing Motive	Participating in the task, playing its role, doing the task
Description of the task	Finding objects and bringing them to the center of the room, pushing objects in the centre of the room

Table 15: The table presents the annotation scheme of the analysis of children's understanding of the robothing behavior.

Direct Reciprocity

The robothing sharing behavior was reciprocated by the children both in form of sharing and in form of instrumental helping that we did not account for. When the robot was taking objects away, the children started to cooperate as a triad, excluding the robothing and we observed spontaneous direct reciprocity between the children. Below, we report the findings per session (Number and direction of the direct reciprocity is visualized in Figure 33).

- **Baseline session:** In the baseline session, participants (C1, C2, C3) independently sorted the objects and did not spontaneously share with each other in the game, despite the fact that each participant (and the robothing too) had objects in their area belonging to the other participants' sorting category. Hence, we did not observe any occurrence of sharing. This falls in the range of our expectations and shows how participants naturally interacted in the task and between the other children.
- **Sharing session 1:** In the first sharing session the robot exhibited sharing behaviors (i.e., sharing objects) with C2. As expected, we observed direct reciprocity behaviors. C2 reciprocated the robot's sharing behavior by sharing an object with the robot two times. Moreover, we observed more direct reciprocity behaviors, from C1 back to C3 after C3 started to help C1.

Figure 33: The figures present the direct and indirect reciprocity findings for the two sharing sessions and for the taking session. The arrows indicate the direction of the reciprocal sharing behavior. Next to the arrow, the type (D means direct, ID indirect) and number of reciprocity acts counted.

- **Sharing session 2:** In the second sharing session the robot exhibited sharing behaviors (i.e., sharing objects) with C1 and C3. We observed direct reciprocity behaviors, but only from one of the two participant recipients (C1 to robothing). However, at further inspection of the data,

we observed that C3 was providing help that we did not account for. I.e., C3 helped the robot adjusting an object's position to accommodate the robot's pushing movement to move objects and participate in the game.

- **Taking session:** In the taking session, we observed an interesting dynamic that was already developing in sharing session 2. Participants (with the exception of C2, see Indirect reciprocity results) seem to participate in the game as a triad (without the robothing) and they start to share with each other and cooperate to complete the game even skipping given turns. We observed direct reciprocity between C2 and C1 ($D=1$), between C2 and C3 ($D=1$) and between C3 and C1 ($D=1$).

Indirect Reciprocity

The robothing's sharing triggered indirect reciprocity, surprisingly already from the first prosocial interaction. In the second sharing session, indirect reciprocity drops. When the robothing is taking away objects children share among themselves, they appear to be playing collaboratively almost as a triad. Only, one of the children (C2) shares with the robothing and tries to include the robothing in the collaborative interaction.

Below findings per session (for a summary of the results see Figure 33).

- **Baseline session:** In the baseline session, participants (C1, C2, C3) independently sorted the objects and did not spontaneously help each other in the game, despite the fact that each participant (and the robothing) had in their area objects belonging to the other participants' sorting category. Hence, we did not observe any occurrence of indirect reciprocity. This falls in the range of our expectations and shows how participants naturally interacted in the task and in the group.
- **Sharing session 1:** In the first sharing session, the robothing shares with C2. To our surprise, we observed a relative high number of indirect reciprocity behaviors. We observed six indirect reciprocity behaviors, two are downstream (C1 and C3 share with the robothing), three upstream (C1 and C3 share with C2).
- **Sharing session 2:** In the second sharing session the robot exhibited a prosocial behavior (i.e., sharing objects) with C1, C3. Surprisingly, we observed a drop in indirect reciprocity behaviors in respect to the previous episode. Only C2 exhibited one indirect reciprocity behavior to the robot (upstream).
- **Taking session:** In the taking session, we observed an interesting dynamic that was already developing in the sharing session 2. Participants seem to participate in the game as a triad, excluding the robothing and independently retrieving objects that the robot would

take away. We observed only two upstream indirect reciprocity behaviors towards the robothing from C2. Two downstream indirect reciprocity (carried from the previous episode) from C2 to C1 and from C3 to C1.

4.4.7 *Tendency to help*

Figure 34: The figure presents an info-graphic to summarize the results of the direct reciprocity in the forced choice help-test. Results are provided per child and per session.

Overall, in line with our expectations, children's tendency to help the robot after the game appears to be influenced by prior behaviors of the robot in the game.

- **Baseline session:** When the robothing exhibited only play behaviors, C2 and C3 did not help the robot in the help-test. Only C1 did.
- **Sharing session 1:** In contrast to the baseline results, all the participants helped the robot in the session where the robot shares with C2.
- **Sharing session 2:** All the participants helped the robothing in the second prosocial session where the robothing shares with C1 and C3.
- **Taking away session:** All the participants (C1, C2, C3) did *not* help the robot in the help-test after they interacted with the robothing taking away objects in the game.

Motivation to help

The interviews suggest that the participants are able to describe their own motivation to be prosocial. They mainly describe their motivation as empathy towards the robot or need to reinforce the norm of cooperation in the game. Below, we report the findings of the motivation to help items per session.

- **Sharing session 1:** All the participants were able to describe the motivation behind their own sharing behaviors. When asked about how they helped the robothing, children describe the sharing behavior as helpful and sharing (C1: *'I helped Kenny by bringing him things from my pile'*, C2: *'I gave him the cubes'*, C3: *'I also helped Kenny. I gave him some things'*). When asked about the motivation to help the robot C1 explained that the robot was in need and that because the robot is nice he wanted to help *'Because he needed the things. He is a very nice robot.'*. C2 (the child the robothing shared with) describes her motive to share as helping each other to finish the game: *'Because we needed 7 things and Kenny did not have 7 things. And me neither. So Kenny gave me the things and I gave things to Kenny'*. C3, like C1, describes the robothing's need of objects as main motive to help: *'Because he had no cubes and I gave him the last one'*. Similar motivations were given when inquired regarding the motive to help the other children.
- **Sharing session 2:** C2 was able to acknowledge and describe her sharing behavior towards the robot. C2 recognized that the robot was in lack of objects and describes the motive to help the robot as follow: *'I gave him a red brick because he had not so many.'*. However, C2 cannot explain why she did not share with the other children *'Actually, I did not help them. I don't know why'*. Surprisingly, C3 states that he shared objects with the robot and the other children in the game, while behavior observations cannot confirm his statement. Similarly, C1 was able to acknowledge and describe his sharing behavior as a helpful act towards the robothing, but he also claimed that he shared objects with the other participants, but behavior observations cannot confirm the statements.
- **Taking session 3:** C2 describes her sharing with the robot as important to finish the game *'Because he [Kenny] needed the things. Everybody had to bring 7 items to the middle.'*. Similarly to the second sharing session, C1 stated that he helped the robothing because the robothing needed objects, but behavior observations cannot confirm the statements. C1 stated he helped the robot (which is not supported by data): *'So that we could play'*. C3 was able to acknowledge that he did not help the robot and that he helped the other children *'only a little'*. When inquired about why he helped the other children, for the first time he provided

an answer that relates to normative behaviors: ‘*Because I should/I had to.*’.

Children’s Understanding of the Robothing Behaviors

Children were able to described their own behavior during all the sessions of the case-study. They distinguish between playing behaviors (i.e., sorting and bringing objects to the dispatch areas) and sharing behaviors, they added a connotation of sharing behaviors as helpful and instrumental to finish the game. Children describe the robothing behaviors as sharing and ascribe a prosocial motive during the sharing sessions and describe the robothing behaviors as playing behaviors with playing motive. Surprisingly, children did not describe the robothing behavior as taking away objects with an antisocial motive. One of the children (C1) described the robothing behavior as sharing when the robot was in fact taking away objects. While the other two participants (C2, C3) described the behavior as playing behavior, without explicitly labeling the robot antisocial or prosocial. Hence, at least two of the three participants recognized that the antisocial robot behavior was different from the sharing behavior in the previous two sessions, but they were not able to understanding the motive of such a behavior.

4.4.8 *Discussion*

Our findings provide initial indications that the robothing behavior has an influence on children’s direct and indirect reciprocity in a game. In addition, our findings provide indications that the robothing behaviors influence children’s tendency to share with each other, even in situations where collaboration is not enforced.

The direct reciprocity findings indicate that the sharing behavior of the robot promoted children’s reciprocity behavior towards the robot and the other participants (**Sub-question 1a**: How does interacting multiple times with a robothing that shares objects influence children’s direct reciprocity). In fact, findings indicate that the robothing’s sharing behavior has influenced the children to share objects back with the robothing, which was not observed in the baseline. This is in line with the literature regarding reciprocity and children [97].

Moreover, the direct reciprocity findings highlight some influence of the robothing’s taking behavior and of previous session’s prosocial interactions with the children on direct reciprocity (**Sub-question 1b**: How does interacting multiple times with a robothing that shares objects influence children’s indirect reciprocity). In fact, in the taking session, children start to collaborate in the game, sharing and directly reciprocating each other, mostly excluding the robot.

Interestingly, the indirect reciprocity findings indicate that the robothing’s sharing behavior influenced the children’s indirect reciprocity behavior

already from the first sharing session. Unexpectedly, indirect reciprocity behaviors drop in the second sharing session. When the robot is taking away objects, children are indirectly prosocial amongst themselves and they appear to be playing collaboratively as a triad. Only C2 still tries to re-engage the robot and seems to somehow 'carry-on' the effect of the previous interactions with the robot. The children appear to be sanctioning the robot's antisocial behavior by stopping to be prosocial towards the robot and cooperating as a dyad or triad.

The robot's prosocial behavior and antisocial behavior appears to not only influence children's prosocial behavior in the task, but also outside the task, in line with the literature [283]. All the participants helped the robot outside the task, during our help test, and after a prosocial session, but they did not help in the baseline and in the antisocial session.

Our findings indicate that group dynamics played a role in children's motivation to help. Children mainly describe their motivation as a form of empathy towards the robot or the need to reinforce the norm of cooperation tacitly established by playing (a known phenomenon in child-child interaction as described in Chapter 2). They seem to consider themselves as part of the same group. This might have supported the emergence of sharing behaviors too, as evidence from developmental psychology suggests that children consider task group members to have social obligations and to behave prosocially towards one another [284]. Children attribute qualities to the robot (e.g., a nice robot) and motivate its actions due to these positive qualities. The tendency to attribute qualities to agents that are behaving prosocially (in our case sharing) has been shown in previous HRI work with adults [62].

Individual differences (personality and social behavior) do not seem to play a role in the case-study findings. However, we have noticed that gender and age factors might have played a role in the behaviors of the two boys. Especially in the second prosocial session, C1 (10 years old) and C3 (7 years old) appeared to have interpersonal conflicts about sharing resources. This is an interesting observation as it might suggest the need to endow the robot with prosocial conflict resolution strategies [319] for further developments.

Design Implications

Robothing's actions appear to effectively communicate a robot's goals and intentions to the children behavior. The robot behaviors were mostly legible to the children whom appeared to parse the non-verbal behavioral cues (i.e., motion) in the way we intended the behavior to be understood, except for the taking behavior. A combination of social gaze-movements to engage in joint attention (i.e., rotation of the robot base) and sharing behavior if well grounded in the game appear to be promising for child-robot interaction. While in general the robothing behaviors appear to communicate well to the children, we have observed discrepancies between children's behavioral

reactions in the task (i.e., reciprocal behavior, cooperative dynamics) and their explanation both of their own behavior and of the robothing. Children understood that the robot was acting with a prosocial intention to share with a child in the game. They labeled the sharing behavior as normative, that it is something that is good to do when playing a game with others. On the contrary, children did not explicitly ascribe an antisocial intention to the robothing's taking behavior. The majority of the children in the cohort described the robothing as sorting on its own, not engaging with them. Children's reported perceptions do not align with the way the children reacted to the robothing's taking behavior. In fact, behaviorally, children reacted negatively: they excluded the robothing from the game and did not share with the robothing anymore. The antisocial act (i.e., taking away objects that are needed in a game) might have been considered as mild, children might consider antisocial only an extreme non-normative behavior. Or else, that the prior exposure to the prosocial behavior contributed to prime the children into considering the robot as 'nice', 'helpful' and 'friendly'.

The findings bring some considerations regarding how children parse and make sense of a robot's behaviors. Children parse the behavior of a robot a little different from the way adults do. Children's unique ways of parsing behavioral cues of a robot and interpreting them to making sense (i.e., attribute intention and react accordingly) of behavior has a great impact on child-robot interactions (cHRI) [25] both in positive and negative ways.

Usually, as in our case, designers and roboticists get insights into how children perceive a robot behavior *after* the design process in the evaluation phase, often observing surprising results. To date, there are no established methodologies to design robot behavior specifically taking into account children's ways of making sense of a robot behavior in cHRI, nor established approaches to translate this knowledge in actual implementable robot behaviors. Future work should take this phenomenon into account.

Methodological Implications

In terms of method, this case-study provides an example of how to approach a longitudinal study to investigate child-robot prosocial interactions. Because longitudinal child-robot interaction in groups are in its early days, it is often challenging to find scenarios and protocols available for researchers.

The case-study posed methodological challenges in terms of measures. We have observed a possible suggestibility effect in the interviews. Children reported that they helped the robot even if they did not (as observed in the video-recordings), most likely to please the researcher. An alternative explanation could be that the children felt guilty that they did not help the robot [91] and they 'repaired' their lack of prosocial behavior by reporting it in the interview. Overall, these methodological implications once again suggest that we should be relying mostly on behavioral observations. Amongst

our behavioral measure, the help test inspired by developmental psychology appear to be successful for this age group.

Limitations

As with any study, there are limitations to our research approach. The case-study method is quite appropriate for an exploratory study as it allows to hone-in and gather in-depth observations of a cohort of participants. However, our findings are limited by our cohort and cannot be generalized. Future work needs to build upon our initial observations and set up an experimental observational study with an adequate sample size. Furthermore, we were only able to examine a specific set of variables, but there are likely many other factors at play when it comes to how children will respond to robothing's sharing behaviors (e.g., group dynamics, affiliation).

Following our framework, we designed robothing behaviors that are heavily embedded in a structured sorting game. As such, the designed robot behaviors might not be applicable in other social interactions and the observed effects might not generalize. Future work needs to investigate multiple settings and task scenarios.

4.4.9 *Study 4: Conclusions*

We carried out an exploratory longitudinal single case-study with a cohort of three children. Our findings inform our framework: we provide first indications that a robothing's sharing behavior can compel children to reciprocate both the robothing and indirectly the other children. We provide preliminary indications that robothing's behaviors promote prosocial behaviors (i.e., reciprocity) and have an impact on the way children collaborate with each other. At the same time, we provide indications that children explain a robothing's and their own behavior in unexpected ways, an aspect that needs to be taken into account in the design of robthings.

4.5 CHAPTER CONCLUSIONS

Chapter 4 investigated how to design a robothing's behavior to communicate in human terms to children in collaborative play. This chapter provides critical contributions to the dissertation.

The chapter informs RQ3 *How should the non-verbal behavior of low/non-anthropomorphic robots be designed to communicate a robot's intention to children?* Our empirical studies provide numerous insights into how well the design principles enable robthings to communicate children's intentions. Study 2 showed that a simple rotation of the base of a robothing is enough to communicate social attention to a child and the intention to refer to an object. Simple rotations towards a person or an object are cues to the helpful intention of the robot too. Study 3 showed that adding non-verbal sounds

to a robothing's motion does not reinforce child-robot communication, but a robothing's actions alone can communicate help-giving intention with locomotion.

In line with our principles, we unveil a non-trivial aspect of 'grounding' [131] and parsing of the meaning of a low/non-anthropomorphic behavior in the interaction that enables the social communication of robothings. Our behavioral studies show that *when* and *after*, *which* action of the children a robothing intervenes has a high impact on the way the behavior is interpreted. Similar to Jung et al. [183], we can observe a parallel with the way humans ground language in conversations, taking into consideration the context in which an utterance is delivered to make sense of it and attribute the correct meaning. Therefore, the sequencing of actions in low/non-anthropomorphic robots' non-verbal behavior appeared to become a sort of '*non-verbal syntax*' and '*non-verbal semantic*'. It follows that the role of the scenario in which the non-verbal behavior of low/non-anthropomorphic robots interact plays a significant role in sense-making. While our principles touched upon the disambiguation of aspects of the interaction scenario to 'ground' the interaction (i.e., ground the recipient, object, and intention of a robothing's action), we did not actively design for non-verbal behavior sequencing. However, we have revealed a relevant feature for a low/non-anthropomorphic robot's non-verbal communication, and our work enables more explorations in this direction.

We anticipate there could be many other ways to design a low/non-anthropomorphic non-verbal behavior to communicate a robot's intention to children, beyond the principles we posited in the dissertation. We are aware that design researchers [299] are exploring different theories (e.g., Actor-Network Theory) and principles to enable non-anthropomorphic products to communicate intention. While our findings might apply only to the cHRI domain and in limited scenarios, we think that we have contributed to an evolutionary broadening of designing a low-non-anthropomorphic robot to communicate in 'human terms' to children.

Our findings inform RQ4. *How do children interpret and perceive the non-verbal behavior of low/non-anthropomorphic robots in play?* Study 2's findings showed that a robothing's minimal motion (i.e., social and deictic gaze-movements) communicate social engagement and helpful referential information to children. Children could accurately understand the legibility of the minimal gaze-movements of the low-anthropomorphic robot, without human-like form or behaviors.

We yield early indications that our framework holds in child-robot interaction at the intervention level, thereby providing insights for RQ6 *What are the effects of a robothing behavior on the prosocial behavior and collaboration of children in play?* Our case-study provides first indications that robothings affect collaborative play dynamics: a robothing influences children's social motives to collaborate and reciprocate one another in collaborative play.

Although we showed that the studies' findings substantiate our interaction design, we know that our interaction design could be a simplified approximation of a very complex social phenomenon. The prosocial dynamics unfolding in play can be far more intricate than in our interaction scenarios. The findings from our in-person studies showed that child-robot interactions in play are more sophisticated than we have envisioned. In Study 4, while children sanctioned the robothing by excluding it from the game because it stopped to share after two game sessions, they still collaborated. At the same time, children did not perceive the robot's behavior as hindering as we anticipated.

To conclude, we learned important lessons about designing *for* children that makes us consider designing *with* children. We have observed discrepancies between children's behavioral reactions in Study 4 (i.e., reciprocal behavior, cooperative dynamics) and their explanation both of their own and the robothing behavior. The findings highlight the importance of considering how children parse and make sense of a robot's behaviors. Children's unique ways to understand agency and make sense of a robothing's behavior might be crucial to design robothing's for collaborative play. Especially because only when the communication of the robothing's social motive is clear children can collaboratively engage with the robothing, possibly reciprocating the robothing's acts behaving prosocially in collaborative play. Since there are no established approaches to translate children's explanations of a robothing's behaviors in the HRI design process, we explore methods and techniques in the following chapter, Chapter 5.

A METHOD TO DESIGN ROBOTHINGS BEHAVIORS WITH CHILDREN

“When you design with, rather than for kids there’s a better chance to come up with a solution that fits the children [...] Easier said than done! When it comes to innovating for others, don’t guess what they want or do what they say: co-create what they—and you—will love once it is there!”

(Edith Ackerman, 2009)^a

^a I suggest to listen to **Gloria and Utopia by Björk** while reading this chapter.

Chapter 5 explores methods to involve children’s perspective of a robot behavior and agency in the design process. In the chapter, we introduce a co-design method to include children in the design of robothings’ behaviors: Perspective Taking in Embodied Role Play (PeerPlay). The PeerPlay method consists of two activities, Exploratory PeerPlay and Behavior Authoring PeerPlay; the former is developed for the initial design process when a robot platform is not defined yet. The latter is geared to mature stages of the design process, during middle and high-fidelity prototyping. The method centers on role-play and perspective-taking, central phenomena in children’s understanding of agency. We co-design and co-generate robothings behavior with Peer-Play while enabling children to reflect on a robothings’ agency. The chapter reports two co-design workshops with children (Workshop 1, Workshop 2) to explore the PeerPlay method.

The chapter is based on the following publications:

Zaga, C., Papenmeier A., Beleen T., Bernard T., Truong K. P. and Evers, V. (2017). *Towards Co-designing Minimal Robot Behaviors with Children: What Children Can Teach Robots*, In *Proceedings of the 2017 Workshop ‘What Actors can teach robots’ at CHI Conference on Human Factors in Computing Systems (CHI ’17)*.

Zaga, C., Truong, K. P. and Evers V., *Co-Designing the Behavior and Agency of Robots with Children: the PERSpective Taking in Embodied Role Play (Peerplay) method (in preparation)*

5.1 CHAPTER INTRODUCTION

Robotic technology for children is designed to behave socially. Robots for children are imbued with behaviors to communicate to children their state and goals and establish communication. The ultimate goal is to design robots that are perceived as agents to interact with. Children parse robots' behaviors and perceive robots as social agents with intentions, beliefs, and desires of their own (agency). However, there is often a discrepancy between what designers want the robot to communicate and how children perceive the robot's communication. Robotic technology is often unable to design children's ways of making sense of a robot's agency in mid.

Let's break down how why and how children make sense of a robot behavior. To interact and communicate with a robot, a child needs to perceive the robot as an agent and explain its behaviors [178]. To be perceived as an agent, a robot should be animate and behave contingently. A child needs to understand which of the robot's behaviors are intentional. Once behaviors are perceived as intentional, a child parses them to elaborate on the intentions, beliefs, and desires of the robot [240]. Understanding an agent's behavior, any agent from humans to artificial agents like robots, is a core component of social interaction, without which it is hard to establish interactions. Based on this understanding, a child decides how to act or respond to a robot's behavior.

Motivation

However, children perceive, explain, and understand a robot's behavior in unexpected ways [26]. Children's behavioral responses to a robot's behavior might not correspond to what the designer intended. Why? Children tend to blur the boundaries between animate and inanimate more than adults, easily endowing inanimate objects with agency [3]. Animate objects, objects that move and behave, make children play even more with the so-called *illusion of life*. While roboticists have used this tendency to facilitate children's engagement with robots, it is undeniable that the way children play with the perceived agency of agents has remarkable effects on how they interact with agents in general and robots in particular [178]. For example, a robot's social behavior deemed to make an interaction more natural could be confusing to children [195], negatively impacting their learning. In other cases, children respond to a robot's behavior positively, but when asked what the robot has done, they negatively interpret the robot's behavior (see Study 4). It is hard for a designer to understand what children perceive and explain a robot's behavior. Survey methods and interviews fall short of understanding children's experiences with robots, but, to the best of our knowledge, they are still the predominant methods to evaluate cHRI.

The gap in the literature

Involving children in the design process of robot behaviors with appropriate methods could provide cHRI designers with unique insights into how children perceive and interpret robot behavior. However, while involving children in the design process of digital technology (child-computer interaction (CCI) literature) is well-understood [89] in cHRI, children are typically

involved only evaluate the cHRI experience. Children rarely contribute to the design and generation of behaviors, apart from some notable exceptions like the work of Alves-Oliveira et al. [7] and Lupetti et al. [235]. In general, in HRI, people’s involvement in the robot behaviors design process is mostly reserved for adults and domain experts, such as movement or theatre experts [332, 355]. In cHRI, another hurdle is the lack of methods designed to deal with children’s agency understanding. Co-design methods are geared to design technology’s physical appearance, functionality, or interaction features in CCI. Robotic technology is not comparable to other digital technology due to the sense of agency that robotic technology evokes. Hence, cHRI needs co-design methods able to account for the agency factor.

*Pretend Play and
Perspective Taking*

To tackle this gap in the cHRI field, we explore co-design methods to involve children in designing a robot behavior. In particular, we focus on developing co-design activities to account for children’s way of making sense of a robot’s agency and facilitate children’s reflection in co-design. Hence, this chapter tackle our fifth research question, *RQ5. What method is suitable to co-design the non-verbal behavior of a robot with children?*. We identify two central phenomena in children’s understanding of agency through perusal of the child psychology and sociology literature: *pretend play* and *perspective taking*. Children are naturally inclined to build stories and characters during pretend play. Through pretense, children make sense of and imagine what the world could be [230]. Through pretend play, children draw and enact fictional scenarios, sketching-out fictional characters. Pretend play is a potent activity that supports children’s development of Theory of Mind, i.e., the ability to attribute mental states to oneself and others, which is necessary to expand their social capacities [140]. Perspective-taking means to make sense of other people’s behavior, predict what people may do or say next, and to think about one’s social behavior and adjust it accordingly. During pretend play, children also need to interpret each other’s pretense: a child must read through the pretender’s actions to his or her intentions, thus taking another’s perspective and making sense of the pretended interaction [230]. Perspective-taking enables a renewed understanding of each other’s agency, and scholars consider perspective taking the cornerstone of children’s sense-making of their interaction with agents [2]. Through perspective-taking, children engage in the necessary process to understand another’s behavior in terms of intentions, beliefs and desires, which is the foundation of any interaction [240]. Pretend play is often used in CCI and co-design practices in general to facilitate co-design activities, in the form of role-play [118], puppeteering or *bodystorming*, brainstorming through body movement [310]. In cHRI, pretend play has also been used to design a robot’s locomotion according to given personality traits [7], in the form of playful puppeteering. However, perspective-taking activities a less frequent, and techniques to enable children’s perspective taking are lacking. Notably, there is less attention to allow children to reflect about taking perspective, which could

Our Co-design Method

be beneficial to gather a better understanding of children’s way of making sense of an agent’s behavior.

Building upon related work and filling the gap of current co-design methods, we developed a co-design method that combines pretend play and perspective-taking to design a robot’s behavior: *Perspective Taking in Embodied Role Play* (PeerPlay). Adding to the current state of art, we combine pretense scenarios with body-storming and puppeteering activities, always followed by a perspective-taking reflection. Children step out of character at the “meta-level” to reflect on the generated narratives and behaviors. The method is developed to involve children as co-designer at specific stages of the cHRI design process: the beginning of the process when a robot platform is not defined yet and scenarios are explored; and the mature phases of the process, when designers are working to implement robot behaviors in a specific robot platforms. Hence, PeerPlay consists of two co-design activities *Exploratory PeerPlay*, for the initial design process, and *Behavior Authoring PeerPlay* for prototyping activities.

In the section’s reminder, we introduce the theory and related work that ground PeerPlay and we elaborate on its development, detailing *Exploratory PeerPlay* and *Behavior Authoring PeerPlay*. We conclude with a reflection. In the following sections, we test and assess PeerPlay in co-design workshops with children.

5.1.1 *Theory and Related Work*

This section introduces and unpacks the theory and related work that informs our co-design method development. First, we give an overview of how children parse, interpret, and explain an agent’s behavior and, ultimately, agency. Then, we hone-in on the phenomena of pretend play and perspective-taking, the cornerstones of children’s sense-making of the agency. After that, we introduce co-design with children and elaborate on the related work in CCI. Lastly, we discuss the related work in cHRI.

How children Explain Behavior and Agency

Children develop in the course of childhood the ability to understand each other’s actions, intentions, beliefs, and desires [17]. Scholars have called this ability to “read” each other’s mind and behaviors Theory of Mind [21]. There are many hypotheses regarding how children acquire Theory of Mind, but children develop this ability while growing up regardless of the various perspectives. Furthermore, they train their abilities through the interaction with others [17].

To interact and communicate with people, a child needs to perceive them as agents and make sense of their behavior [240]. The scholars working on Attribution Theory [240], the psychological model of behavior explanation, and children’s Theory of Mind illustrate how a child needs to understand which of the behaviors he/she perceive are intentional and parse them to realize the underpinning intentions, beliefs and desires the child eventually attributes to a person [240]. Understanding a person’s behavior is a core component of social interaction, without which it is hard to establish interactions. Based on this understanding, a child decides how to act or respond to a person’s behavior.

Typically, in adults, the concept of intentionality facilitates the explanations of behavior. Adults explain intentional behaviors by giving reasons for the behavior. By giving reasons, adults unpack the beliefs and desires to explain a particular behavior that they deem intentional. On the other hand, unintentional behaviors are explained by physiological, biological, or cultural causes. Sometimes people explain intentional actions using the causal history of reason explanations, referring to how reasons develop and enabling factor explanations that describe an agent’s skill [240].

In contrast, children appear to blur between attributing mental states, reasons, or causes [125]. Children appear to apply mental state explanations broadly to human behaviors and learn later in development to distinguish between reasons and other mental causes [314, 21]. This dis-entanglement between psychological and physical description when explaining behavior greatly affects how children perceive and explain an agent behavior, like the behavior of a robot [2]. Edith Ackerman explains that: “*The most striking characteristic of this synthesis is children’s focus on ‘who’ is impacting ‘whom’ (and*

how), and ‘*who*’ is impacted by ‘*whom*’ (and *how*) in a given transaction. Both people and things are understood in terms of how they control each other’s behavior, either through direct or mediated action”[2]. Thus, children consider agency as a form of control over another’s behavior, which explains children’s tendency to blur the boundaries of animate and inanimate easily: anything that self-propel is an agent to whom attribute physical and psychological reasons for behaving [3]. Ackerman calls this phenomenon “agency of transactions”, a perceptual and explanatory chain in which things, people, and artificial agents like robots are seen as alive or inert depending on who initiates an action and who is the recipient of the action.

All in all, children tend to blur the boundaries between animate and inanimate more than adults, easily endowing inanimate objects with agency. Adults can play with the illusion of life and suspend disbelief, but children systematically up until ten, eleven years old [281]. The literature shows that playing with the concept of agency is children’s way to make sense of it and develop their Theory of Mind. Playing with the *illusion of life* is beneficial for children, but when designing robots for children, the role of children’s explanation of behavior and understanding of agency should be considered more.

Pretend Play and Perspective Taking

By engaging in pretense and perspective-taking, children naturally train their understanding of agency (the agency of transactions as explained in the above section) [230, 1]. Pretense is an activity that all children engage in; children as young as three years old engage in pretend Play. Lillard describes pretend-play as “[...] a remarkable cognitive feat: the child’s mind purposely thwarts reality, making things other than they are, at an age when the child is just learning what reality is” [230].

In Pretend Play, children imagine to be somebody else, or that an object is something else that it is [29]. Children build narratives about imaginary people and objects both by playing alone or by playing with other children. In Pretend Play, children could role-play, sketching characters in imaginary worlds or symbolically-play imbuing objects of a character or characteristics that the object does not usually have [231]. During pretend-play, children also need to interpret each other’s pretense: a child must read through the pretender’s actions to his or her intentions, thus taking another’s perspective and making sense of the pretended interaction [161]. It follows that the cognitive skills key to pretend-play are the ones that enable the understanding of agency and the development of Theory of Mind: social referencing (i.e., using another person’s response to an ambiguous situation as a guide for one’s response); interpretation of underlying intentions; symbolic understanding; and understanding alternative representations of the world [230].

Perspective-taking means to make sense of other people's behavior, predict what people may do or say next, and to think about one's social behavior and adjust it accordingly. In other words, perspective-taking means managing various view-points, drifting-in, and outs of them. Children use perspective-taking to make sense of the world, of others and develop empathy [1]. Perspective-taking enables a renewed understanding of each other's agency: by diving-in a point of view, children try to make sense of another's psychological state putting themselves in the shoes of another; by stepping-out that point of view, they reflect on it to gather a broadened understanding of the situation [1].

Overall, we identify two central phenomena in children's understanding of agency through the perusal of child psychology and sociology literature: Pretend-play and perspective-taking. Pretend-play and perspective-taking go hand in hand to enable children to understand humans' agency and make sense of others' behaviors. They both represent a natural "developmental gym" to train their ability to read, interpret, and understand others while they are growing up. For the above reasons, pretend-play and perspective-taking are uniquely positioned to facilitate children's generating and reflecting on an artificial agent's behaviors.

Co-design with Children

Collaborative design or co-design is a subset of participatory design in which designers and researchers work together with children on a design problem [330]. Citing Marc Steen [349]: *"Co-design can be understood as an attempt to facilitate users, researchers, designers and others – or: diverse people with diverse backgrounds and skills – to cooperate creatively, so that they can jointly explore and envision ideas, make and discuss sketches, and tinker with mock-ups or prototypes"* (page. 52).

Co-designing with children means involving children throughout the whole design process or during specific design iterations with the scope to ensure that children's needs and point of views regarding a product or technology are met [133]. Several scholars has adopted co-design with children in CCI to involve children in the design of technology, with the pioneer of this sub-field being Alison Druin and her work at the University of Maryland. Hourcade, in his review of the CCI field, defines co-design technology with children as *"the study of design, evaluation, and implementation of interactive computer systems for children, and the major phenomena surrounding them"* [159].

The core motivations to include children are empowerment, knowledge gap between researchers and children, and better design outcomes. Involving children in the design of technology helps to understand children's needs better, but it also enables children to have a voice on the technology surrounding them [102]. Co-design is meant to empower children in having a say in the development of technology by providing them with developmen-

tally appropriate instruments to communicate their perspectives to adult designers. Co-designing with children stems from the idea that children are an entirely different user population with their own culture, norms, and complexity as they are humans in *'fast-paced' development* [89]. Within this perspective, children are treated as experts with special knowledge of their own experience of *'being a child'*. CCI research has argued that involving children leads to design outcomes that are better adjusted to their needs and that are different from what researchers would have come up with [89].

Children are involved in the design of technology at various levels. Druin [88] identified the core roles a child can take, as users, testers, informant, and partners. When children are users, children are research and design subjects. Children take the role of testers when they are called to evaluate technology designed by researchers. Children informants are involved in specific moments of the design process to provide input and co-design with the researchers. Informant design is intended to be a compromise between working with children as full partners and adults designing technology with children in mind. Children are partners when they participate in the whole design process. Thus, children role's go from full involvement with design partnerships to a minimal involvement as tester [88]. The level of partnership differently shape the technology design process and impact the technologies that are created. Recently, scholars have identified two additional roles in the design process: co-researcher and protagonist. While co-researcher [82] bring children in a symmetrical role with the researchers co-developing research questions, the role of protagonist [169] is meant develop children's critical and reflective stance toward technology and skills for designing technology.

Druin [89] defined three dimensions of the role children take in technology: relationship to developers, relationship to technology and goals of inquiry. Children relate to developers elaborating ideas or prototypes in dialogue, providing feedback. Children's relationship to technology spans from having ideas about the technology to co-creating prototypes and full products. The goal of inquiry could be developing theory, questioning the impact of technology, or better user experience design. Following the taxonomy of Johansson and Van Doorn [82], children can be involved in many aspects of the design process: children could participate in the "stage", i.e., explore the design space and gathering data to explore the opportunity of design, they could participate to collaboratively "evoke", i.e., that is to explore concepts and scenarios, they can be involved to "enact", i.e., to explore a design idea tangibly, making prototypes or acting out scenarios.

Overall, co-design could represent a fruitful approach to involve children's in the cHRI design process. While co-design with children is an established CCI approach, cHRI has just started involving children in the process. However, the methods and techniques developed in CCI might fall short for cHRI. Traditionally, CCI methods have not focused on facilitating

children’s elaboration of their understanding of agency because – arguably – issues related to agency are less prominent in CCI than in cHRI.

Related Work in CCI

In CCI, there are many methods and techniques to involve children in the Design Process. Depending on the level of involvement of children, scholars have developed methods to explore scenarios [102], prototype interfaces, or go through a whole technological development [88].

CCI is mainly focused on designing digital products [289], computer interfaces or tangible computing objects [12]. To the best of our knowledge, CCI has not yet developed co-design methods to co-design a robot’s behavior. Tool-kits and platforms have been developed to provide children with the instruments to design the behavior of interfaces [294] or to develop simple machine learning algorithms, and training AI models [87]. There has been an example of the application of cooperative inquiry to co-design robots with children but without a particular focus on discerning how children make sense of a robot’s behavior [14].

Despite the lack of CCI work concerning the co-design of robot behavior, there are many techniques based on pretend-play and perspective-taking related to the scope of our research. Enacting and pretense inspired techniques have been extensively used in co-design activities in CCI [118, 308] to support children’s construction of meaning by acting in the world and taking perspective. Many of these techniques come from drama and storytelling practices. Pretense inspired techniques seem to suggest that performative methods are particularly suitable for children because they encourage children’s natural tendency to use pretense to playfully make sense of the world surrounding them, thus promoting a high degree of expression and creativity. Hence, enacting techniques can help children think and make sense of a robot’s behavior. Within this perspective, Giaccardi et. al., [118] and Antle et al., [12] advocate the use of methods that enable children’s embodied experience of interaction with computational artifacts. For children, using their bodies to construct meaning through action is fundamental to unleash creativity and bridge adults’ and children’s capabilities.

There are many examples of embodied co-design techniques based on pretend-play and perspective-taking. For example, concept evaluation by acting out use via scenarios [316]; embodied and performative techniques inspired by role-play, like body-storming [271]; physical-sketching [77, 144]; and embodied narratives [118] through which children are encouraged (usually in groups) to use their bodies to generate ideas by performing. Role-play techniques like bodystorming and embodied narratives allow children to contribute on a multi-modal level, i.e., verbally and through physical actions. The multimodality of bodystorming is particularly important because children have difficulties making concrete verbal descriptions of physical actions. Symbolic-play inspired techniques, like Puppet-Based

Design technique [308] involves the use of puppets and other props to facilitate “pretending and enactment” of ideas. Both techniques usually use imaginary scenarios, vignettes, or cards to guide the activities and the creation of ideas and prototypes. Tools and props are also used to re-create scenarios and situations.

Shaper and colleagues [308] suggested that role-play and symbolic-play have different effects on children’s abilities to reflect on technology and design solutions. They noted that designing with puppets (i.e., symbolic-play) helped children reflect upon their knowledge of gestures in an interactive playground. By taking a second person perspective and facilitating children’s expression of how the technology should behave, children were able to generate gestures meaningful to them. The authors noted that a balance between ‘getting immersed in a situation’ and ‘stepping back’ from it [1] is needed because these activities might play a different role in perspective-taking.

Related Work in cHRI

In cHRI, co-design is not a widespread method. Typically, CHRI focuses on user-centered methodology wherein children are involved in the design process as a tester of the robotic technology. Hence, in cHRI research, insights about children’s perception of a robot behavior are typically gathered at the end of a design cycle.

However, there are a few examples of the use of co-design in cHRI. Scholars have resorted to co-design to define the context of a robotic intervention [30], to design a robot platform and its interaction with children [235, 14, 6] or to gather insights to create a robot’s physical appearance [402]. To the best of our knowledge, only Alves-Oliveira and colleagues [7] have tapped into pretend play methods to design robot motion trajectory according to human personality traits. The authors invited children to prototype various robot personalities by symbolically puppeteering with a low-fi representation (i.e., a paper cube). Children created several motion trajectories according to a robot’s imagined personality. However, the technique used by Alves-Oliveira and colleagues [7] is not geared to understand children’s views on a robot’s agency, but rather to involve children in the design of the movements of a robot.

Co-design is more common in general HRI with adults. However, there are not established practices yet. One of the most notable examples of the use of participatory and co-design practices in HRI is Lee and colleagues’ work [220]. The authors have explored how to co-design socially assistive robots with older adults to design robots according to people’s issues and concerns and older adults’ understanding of a robot’s capabilities. Another line of co-design research in HRI concerns the involvement of experts of movement in the design process to co-design a robot’s motion. HRI researchers often consult experts to co-design expressive robot motion, and other non-verbal

behaviors [150, 355, 332, 358]. In HRI, experts use role-play techniques derived from acting or choreography to design a non-verbal robot behavior, pretending to be the robot and translating this pretense in movements, vocalizations, expressions to be implemented in the robot. [358, 332]. Experts are invited –for instance– to enact movements or vocalizations depending on a set of robot’s emotions [241] or to improvise interaction sequences for specific robots [150]. The outcomes of these co-design sessions with experts are usually resulting in a battery of (i) motions, later analyzed with the lenses of specific frameworks and (ii) interaction sequences (i.e., a pattern of non-verbal behavior organized in series).

All in all, to the best of our knowledge, co-design in HRI is not widespread apart from notable examples like [7]. Interestingly, both cHRI and HRI utilize embodied pretense to generate robot’s behaviors, involving experts of body movement and vocalizations.

Theory and Related Work: Conclusions

In this section, we have unpacked the way children make sense of agency and explain an agent’s behavior. Children blur the boundaries of inanimate and animate. They tend to attribute psychological state and reason explanation of anything that appears self-controlled to them. Pretend-play and perspective-taking are the central phenomena in developing their understanding of the agency, supporting children in explaining their perspective about a person or an agent.

Co-designing with children has been proven to be an excellent approach to ensure that children’s point of views is integrated into the design of children’s technology [88]. By working together on a design problem, children and researchers generate a design solution and reflect on it. Co-designing could be an approach to involve children’s ways of making sense of robot behavior in the cHRI design process. However, there is a methodological gap to fill. In CCI, existing methods are geared towards computational technology that does not grapple much with the technology agency. In cHRI, co-design is still in its infancy; hence the literature is relatively scarce, and so are available methods.

However, both the CCI literature and the few examples from the cHRI literature point us towards incorporating pretend-play and perspective-taking activities, significantly leveraging their performative facet in embodied fashion. We take these indications for the literature into account to develop our co-design method.

5.1.2 Perspective Taking in Embodied Role Play

This section introduces a co-design method we developed, building upon theory, and related work. To tackle this gap in the cHRI field, we explore co-

Figure 35: In the figure, a visualization adapted from the Convivial Toolbox by E. Sanders, P.J. Stappers [348] to be applied in cHRI. The Figure visualizes what type of knowledge co-design is able to bring to the surface.

design methods to involve children in designing a robot behavior accounting for children’s making sense of a robot’s agency.

We capitalize on pretend-play and perspective-taking as the main dynamics around which to develop a method to involve children in the cHRI design process. Notably, we focus on *embodied role-play* and *perspective taking* activities which literature indicate as appropriate to unlock children’s creativity. We have seen that children quickly turn any agent into a creature, an entity with intentions, minds, feelings, and personality *relating* to it as if it was alive. Though we are aware that children’s tendency to play with “illusion of life” could be negatively deceptive, we believe that engaging children in a pretense scenario of “make-believe” offer pretend play and perspective-taking dynamics to “*suspend disbelief*” in fruitful ways. Our position, grounded in the CCI literature, is that by involving children in generative activities in cHRI we surface children’s knowledge about a robot’s behavior (and ultimately agency) that would not be easy access for researchers with other methods. Thereby bridging the knowledge gap between researchers and children and giving a voice to children in the cHRI process (See Figure 35). Moreover, we believe that the behaviors generated by children might lead to better design outcomes.

To this end, we combine pretend-play and perspective-taking to design a robot’s behavior. We call our co-design method: Perspective Taking in Embodied Role Play (PeerPlay). Adding to the current state of the art, we combine pretense scenarios with body-storming and puppeteering activities. These activities are paired with reflections through perspective-taking. Children step out of character the “*meta-level*” to reflect on the generated narratives and behaviors. The method is developed to involve children as co-designer at specific stages of the cHRI design process. Children co-design

at the beginning of the process when a robot platform is not defined yet. Children are then involved during the mature phases of the process when designers are working to implement robot behaviors in a specific robot platform. Hence, PeerPlay consists of two co-design activities: *Exploratory PeerPlay* for the early design process and *Behavior Authoring PeerPlay* for prototyping activities. Below, we detail the dimensions and characteristics of PeerPlay, and then we hone-in Exploratory PeerPlay and Behavior Authoring Peer Play.

5.1.3 PeerPlay: Dimensions and Characteristics

We combine the dimensions developed by Druin [89], and the ones of the FACIT PD framework [387] to describe the characteristics of PeerPlay. The FACIT framework can provide a common ground around which researchers from various fields and working with different methodological philosophies can communicate (or replicate) a new method or technique. The framework's dimensions include the design goal, i.e., what is the scope of the method; the stage of the design process, i.e., when the method is used in the typical process of designing a robot and its behaviors; the role of the children, i.e., how the children are involved and which tasks will they perform; the role of the researcher, i.e., how are the researchers involved and which task will they perform; the design space, i.e., the dimensions of the design taken into consideration while co-designing; relationship with technology, i.e., what will children design; co-design process, i.e., the series of activities undertaken; Facilitation, i.e., how children will be supported by adults during the co-design process; cost and portability, i.e., the expenditure of executing the method and how much the method adapts to various settings; Below, we illustrate the characteristics of the method per dimension.

- *Design Goal*: The goal of the co-design method is to co-design a robot's behavior and reflect on it. Ultimately, we would like to surface children's tacit and latent knowledge about how a robot behavior express intentionality and agency. In turns, by surfacing children's tacit knowledge, we get a window in children's behavior explanation process, which is potentially beneficial to understand better how to design robots behavior *for* and *with* children.
- *Stage of Design Process*: The method focuses on the early stage of the design process of a robot's behavior and the latest stage of the design process of a robot's behavior. In the early stage of the design process, a robot platform is not chosen or designed yet. Only the robotic intervention is defined by the researchers, e.g., robots to support collaboration. In cHRI, the early stage of the design process consists of conceptualizing a robot's behavior from the literature on human-human interaction, observation of human behavior, or animation/improvisation of the behaviors. We invite children to generate the robot's behavior by

engaging in pretend-play inspired enactment in our method. Hence we are closer to the animation/improvisation practices. The latest stage's design process is the stage before empirical evaluations when designers implement robot behaviors in a robotic platform. Authoring means implementing and testing the robot's behavior in the robot platform. Depending on the platform, designers use either visual or traditional programming environments. Those environments are not very accessible to children due to their complexity. Hence, we aim to involve children with an activity attuned to their cognitive and motor development.

- *Role of the children:* Children are involved in the design process as informants at the beginning and the end of the design cycle of robot behaviors design. Children do not need prior knowledge to participate in co-design activities, but we actively work to level the knowledge gap offering tasks attuned to children's development.
- *Role of the researchers:* Researchers are facilitating children's co-design activities. Researchers do not take an active role in the activities but administer them and try to scaffold children understanding of them. Thus, the intervention of the researcher during co-design is low. Researchers define the scenarios and scope of the design activities.
- *Design Space:* The design space in which children co-design is specific. Children co-design for one particular robotic technology, in our case, a robothing, in a pre-defined scenario given by the researcher.
- *Relationship with technology:* Children co-design prototypes of robot behaviors, either early conceptual prototypes or physical prototypes in an authoring environment.
- *Co-design process:* We envision a co-design process consisting of cycles of diving-in a robot's point of view to imagine the robot's behavior (1st person perspective) and stepping-out a robot's point of view to visualize the robot's behavior (2nd person perspective) both ending with a reflection on the outcomes of each cycle. To facilitate this process, we leverage the playful diegetic tendency of children, i.e., the tendency to narrate stories through pretend play. We take embodied role-play as the main diegetic activity, focusing on children's role-play with their bodies or with symbolic proxies, such as puppets. At the end of embodied role-play activities, children step out of character at the "meta-level" to reflect on the generated narratives and behaviors. Hence, our co-design method focus on the co-design dimension of enacting, making concepts tangible, and produce prototypes.
- *Elicitation:* We elicit the co-design activities by providing children with scenarios, a narrative frame, and a prompt. Providing children

with context and materials is customary in CCI to support children’s generative activities.

- *Facilitation*: We facilitate children’s co-design actively, providing children with a specific structure of the co-design process, elicitation materials, and tools to carry out the activities. We strive to scaffold children’s participation in the co-design activity; we do not actively participate in the activity as researchers.
- *Cost and Portability*: The method is low-cost and portable. The first part of the design process’s activities leverage low-fidelity representations of the robot’s behavior (i.e., puppets); hence, they could be done in many settings and with low-cost materials. The authoring activities might be more costly as they involve a functioning robotic platform and technology to implement that platform’s behaviors. While more expensive, children can do authoring activities outside the laboratory; this activity is also relatively portable.

Exploratory PeerPlay

Exploratory PeerPlay addresses the early stages of the design of a robot’s behavior. At this stage, researchers have not defined a specific robot platform yet. Still, they have ideas on the interaction between children and robots and the robot’s intervention on children learning or interactions.

The activity revolves around a cycle of “diving-in”, “stepping-out”, and reflection. Building on the CCI and cHRI literature on the matter [6, 235, 308], and on the theory of pretend play and perspective-taking, Exploratory PeerPlay thus consists of three exercises: (i) role-play a robot behavior with the body in a given scenario (“diving-in” with a first-person perspective, the child is in the “shoes” of the robot); (ii) role-play a robot behavior with a puppet in a given scenario (“stepping-out” taking a second-person perspective, observing the robot in a scenario); and (iii) reflecting on the role-play outcomes (the meta-level of the co-design activity). Role-play is an embodied activity. Children engage in *bodystorming* and *puppettering*. By focusing on embodied exercises instead of purely imaginative exercises, we help children tap into their knowledge through a process of cognitive unloading [12] of their ideas into physical behaviors. By embedding the embodied exercise in a narrative, we enable children to tap into pretense mechanisms, which we have shown to be crucial to make sense of the agent’s behaviors and agency. By asking them to reflect on the behaviors children have generated through these two exercises, we ask them to explain an imagined robot’s behavior and elaborate on the behaviors’ underlying intentionality, thereby reflecting on the robot’s agency. These exercises tap into the ways children make sense of an agent’s behavior to surface their considerations and views on a robot’s agency.

Role-play with the body is a propedeutic (preparatory) activity to help the children put themselves in the robot's shoes. Hence, role-play with the body does not generate a low-fi prototype of behaviors but only helps children enter the most fruitful perspective-taking mindset. Role-play with a puppet is the main prototyping exercise of the activity. To facilitate the cycle of "diving-in", "stepping-out", and reflection, we provide children with a scenario, and we make the reflection playful. Children receive cards and props to re-create a specific interaction scenario in which children and robots interact. Plus, we give an array of general actions the robot could exhibit in the scenario without specifying the action's intention. To make the reflection playful, we invite children to explain each other designs trying to guess what actions, intentions, and emotions the behavior might express.

The envisioned outcome of Exploratory PeerPlay are a number of low-fidelity robot's behaviors and reflections about the behaviors. The ultimate goal is stimulating children in expressing their point of views about how a robot behavior, how behaviors communicate the underlining intentions of the robot and explain the robot behaviors. In so doing, children tap and communicate to designers their perspectives on a robot's agency.

Behavior Authoring PeerPlay

Behavior Authoring PeerPlay is a co-design activity for the last stages of designing a robot's behavior. Researchers have defined the robot platform to work with and the desired interactions between the children and the robot. Designers might have an idea about the type of behaviors to implement, but they would benefit from incorporating children's perspectives. As such, we imagine Behavior Authoring PeerPlay as a stand-alone co-design activity or an activity in combination with Exploratory Peer-Play.

Behavior Authoring, like Exploratory Peer-Play revolves around cycles of "diving-in", "stepping-out" followed by reflection. It stems from pretend play and perspective-taking, but it focuses more on pretend play's imitative aspects than Exploratory Peer-Play does. When children engage in pretend play, they make objects imitate each other imaginary behavior to build a narrative. Thus, the activity consists of two exercises: (i) authoring robot behavior by making the robot imitate the behavior of a proxy (ii) observing the robot behavior designed to make sense of the behavior in a narrative context (ii) reflecting on the outcomes (the meta-level of the co-design activity). In this activity, role-play equals puppeteering a proxy puppet. The proxy puppet is a tangible remote controller of the original robot platform. Hence, children engage in kinesthetic imitation. Children manipulate symbolically an object to simulate the behavior of an agent using a proxy. Children take a second person perspective by puttering the proxy to make the robot imitate the proxy's behavior. When children step out and observe how the robot's behaviors unfold, they take the third-person perspective. Taking the third-person perspective stimulates in-depth reflections about the intentions

Figure 36: In the figure, a visualization of the PeerPlay method projected on the design process phases.

of the robot. Behavior Authoring revolves around cycles of “diving-in”, “stepping-out” followed by reflection as Exploratory PeerPlay. To facilitate the activity, we provide children with a scenario, and we make the reflection playful. Children receive a set of scenarios and actions the robot takes in the scenarios without specifying the robot’s intention.

Behavior Authoring PeerPlay facilitates the design of a robot’s behavior in an interaction sequence and stimulates children’s reflection. Hence, while Exploratory PeerPlay might yield some low-fi behavior elements, Behavior Authoring PeerPlay yields a set of readily implementable robot behaviors.

5.1.4 A method to Co-design Robot’s Behavior with Children: Conclusions

In this section, we have introduced Perspective Tacking in Embodied Role-Play (PeerPlay), a co-design method to explore and author the behavior of robots, based on the theory of role-playing and perspective-taking. The method consists of two activities: Exploratory PeerPlay and Behavior Authoring Peer Play. Both activities have a vital reflective component to help children assess each other design and surface each other point of view on a robothing’s agency.

In our method, children are not full partners of the designers yet, but they are called-in at specific stages. Although a children-partner or protagonist role could lead to the children’s higher empowerment, we deem those roles as too complex to render for cHRI at the current state of the art. Children are informants that participate in pretend-play and perspective-taking based activities attuned to their development. Pretend play activities are role-playing in the form of *bodystorming* or puppeteering. In other words, children make use of their body and the manipulation of objects to

prototype a robot's behaviors in a low-fidelity (Exploratory PeerPlay) and middle fidelity (Behavior Authoring PeerPlay) fashion.

The ultimate goals of the PeerPlay method are (i) stimulating children in expressing their point of view about how a robot behavior, how behaviors communicate the underlining intentions of the robot and explain the robot behaviors to researchers to elaborate on the way children make sense of them. In so doing, children tap and communicate to designers their perspectives on a robot's agency (ii) Providing insights about how a robot should behave to communicate specific intentions in the form of low or middle fidelity robot behavior prototypes. (iii) Integrating into the design of a robot's behavior children ways to make sense of a robot's behavior, ultimately producing robot behaviors that reflect children's perspective.

Even though the method is developed with children in mind, we need to understand how well it works in practice, the outcomes the method yields, and the hurdles of co-designing with children. Hence, we operationalize both Exploratory PeerPlay and Behavior Authoring PeerPlay in two workshops to evaluate them with children.

5.2 WORKSHOP 1: EXPLORATORY PEERPLAY

We evaluated Exploratory PeerPlay in a workshop with elementary school children. In this section, we report the workshop and discuss the findings.

We sought to understand whether the activity supports children in generating a robot's behavior and reflecting upon it. We evaluated both the co-design outcomes in terms of behavior design and the reflections of children. We operationalized Exploratory PeerPlay for a specific design question related to our research, namely designing a robothing's non-verbal behavior to communicate prosocial, antisocial, and passive intentions to children.

5.2.1 *Workshop Method*

We organized a workshop to evaluate Exploratory PeerPlay with children. Workshops are often used in design research to try and test techniques and methods. The workshop's goal was twofold: (i) examining what co-design outcomes children realize through Exploratory PeerPlay (ii) examining what reflections Exploratory PeerPlay yield in children. All in all, we sought to understand whether PeerPlay bridges the knowledge gap between designers and children and provides a window into children's sense-making of a robot's behavior.

A tangent goal was to gather insights about how children would design a robot's non-verbal behavior to be prosocial, antisocial, and passive in

Figure 37: In the figure a representation of how we operationalized the Exploratory PeerPlay activity in the workshop.

collaborative play. This facet of the workshop further developed in Chapter 6.

Participants

The workshop was organized with 20 children participants. Children were pupils from an elementary school in Ede (NL), where education is Dutch. The children are part of a program for gifted children. Children age ranged between 9 and 10 years ($m = 9.3$, $sd = .45$); 9 of the participants were female. 76% of the participants had seen a robot in real life before; 55.6% reported to have played at least once with a robot. Through the teachers' account, we know that participants are used to collaborative activities such as collaborative music-making and art-making. Still, they have never participated in a co-design activity before.

Ethics

The ethical committee of the Faculty of Electrical Engineering, Computer Science, and Mathematics of the University of Twente and the ethical committee of the elementary school of the children both approved the workshop. The children's guardians gave consent to the children's participation. Before the co-design workshop, all the participants attended an informative session with the researcher, after which children gave verbal permission to participate in the workshop. Only one child left the workshop due to illness.

Exploratory Peerplay: Operationalization and Scenario

The Exploratory Peer-Play activity was operationalized as follows. Children engaged in two exercises, (i) role-play with the body and (ii) role-play with a puppet. The practices support embodied pretend-play and perspective-taking by involving children in the enactment of scenarios and robot behaviors. Researchers give the children a scenario in which an imaginary robot interact with two children. The scenario describes the interaction context and the fictional interactions of the imaginary robot. After each enactment, children reflect on each other executions asking questions about what they perceive the intention enacted is. Researchers provide children with questions to ask to prompt the reflection.

Children do the co-design exercises in groups of either dyads or triads. After familiarizing the researchers and the children with a warm-up activity, children start with role-playing with the body. Role-playing with the body is a propedeutic activity to facilitate children putting themselves in the imaginary robot's shoes and reflect on that. It activates the children to take perspective. Each child, in turn, plays the role of the robot or one of the children. After this exercise, children start role-playing with a given robot puppet. Role-playing with the puppet is the primary generative exercise of Exploratory PeerPlay. By puppeteering, children "design" robot behaviors taking a second-person perspective. After puppeteering, children reflect on each other "design". They interpret the puppeteering to elaborate on what goal-directed behavior the puppet enacted, the robot puppet's perceived intention, and the robot puppet's perceived feeling in the situation. By asking each other questions about how each child has puppeteered the robot puppet, children explain the robot puppet behaviors in the scenario, elaborating on perceived goals, intentions, and feelings of the imaginary robot, thereby tapping into the way they perceive agency.

We developed an interaction scenario in which to situate the fictional interaction with the imaginary robot. The scenario focuses on a collaborative play activity between two children and a robot. For the imaginary robot, we envision three possible behaviors based on the literature introduced in Chapter 2: a prosocial behavior, i.e., helping the children; an antisocial behavior, i.e., hindering the children; and, a passive behavior, i.e., sorting independently without interacting with the children. These behaviors refer to children's tree basic responses in collaborative play (In Chapter 2 and Chapter 3, we have covered these concepts extensively). We are interested in seeing how children would enact the behaviors, which action they will choose, and how they will explain the behaviors and, ultimately, agency. Hence, we aim to provide the children with a high-level description of these behaviors, not prescribe a particular action or bias the children in thinking about one specific intention.

Exploratory PeerPlay Materials

Figure 38: In the Figure, we detail the materials of the Exploratory PeerPlay Workshop.

Figure 39: In the Figure, children engaged in Exploratory PeerPlay. Particularly, we show the Role-Play with the puppet exercise in which children puppettered the robot non-verbal behaviors, and the Refection exercise in which children took perspective and explained each other designs.

Materials

First, we created a set of cards to provide the children with the scenario and the robot behaviors to enact. We made a scenario card in which we describe the scenario. The description was as follows: *“a robot and two children, called Jip and Femke, landed on the planet Mars. Their space shuttle is damaged, and it needs batteries. Batteries are scattered all around the planet. Jip and Femke are trying to collect them all”*. We developed robot cards in which we describe each one of the possible behaviors of the imaginary robot. The descriptions were general enough to not prime and bias the children and support children’s enactment. The illustrations were as follows: (i) The robot gives batteries to them, (ii) the robot takes away batteries from them, or (iii) the robot sort the batteries independently. For the role-play with the body exercise, i.e., the preparatory activity, we have created children’s cards, as children take the children’s role too to step in the children’s shoes in the

Figure 40: In the Figure, children engaged in Exploratory PeerPlay. Particularly, we show the role-play with the body exercise in which children enacted the given scenario using their body to set the perspective taking mindset and the role-play with puppet exercise in which children enacted the behaviors with a puppet in a scenario.

scenario. We thought of two imaginary children using common names in the Netherlands: Femke is a helpful child, sharing objects with the robot, and Jip is a less helpful child playing independently from the group.

Second, we created cards to provide the children with questions to ask each other during the reflection after the role-play exercise with the puppet. The questions come from the literature of behavior explanation. [240]. We included a “what” question about the goal of a behavior; a “why” question about the behavior’s perceived intention, and an affect-related question to see whether children ascribe affect to the robot puppet’s movements. The questions were as follows: (i) What did the robot? (Wat deed de robot?), (ii) Why the robot did that? (Waarom deed de robot dit?), (iii) How did the robot feel while doing this? (Hoe voelde de robot zich terwijl Hij dit deed?). After the role-play with the robot (i.e., the preparatory activity), children share the experience of feeling like a robot, but they do not engage in behavior explanation.

Lastly, we made props to make the enactment more vivid and engaging. For the Role-play with the body exercise (i.e., the preparatory activity), we prepared a carton box children could wear to “step in the shoes of the robot”. For the Role-Play with a puppet exercise, we designed a scenario poster onto which children puppeteered. The poster shows the planet Mars, the shuttle, and the two imaginary children, Femke and Jip. We made a Styrofoam puppet with which children could puppeteer. The puppet has a conic shape, easy to be handled by children. The puppet does not have many features besides a blue felted dot to signal the puppet’s front and two felted beads to signal the sides. The shape of the puppet is geometric, and the color is white. We purposely chose not to add anthropomorphic features or distinct

robotic features to lower biases and priming. We used wooden blocks to represent batteries to sort, and we gave each child ten wooden blocks.

Setup and Protocol

The workshop was set in a dedicated room adjacent to the primary classroom. The room had two areas: one area to role-play with the body and one for the role-play with the puppet. We placed two cameras in the room. An action camera on the ceiling and a steady camera in front of the role-play with the puppet area. Children stood in the role-play with the body area and sat in the role-play with the body area.

A researcher and a facilitator conducted the workshop. The facilitator's native language was Dutch. She had extensive experience with elementary school children and with facilitating co-design sessions. Her primary role was to coordinate the workshop and communicate with the children during the exercises. The researcher observed the workshop and had minimal interaction with the children. The children's teacher was not in the room but came in to bring in the children. Children did the workshop in dyad or triad, and we dedicated an hour session solely to one dyad or triad.

The workshop protocol was as follows: The facilitator and the researcher welcomed the children and introduced them to the workshop's activities. Before starting with the exercises, children did a warm-up imitation game: standing in a circle, each child did a movement they like, and the others imitated it. The warm-up exercise's goal was to put children at ease and to get familiar with the facilitator. After the warm-up, children would start with role-playing with the body, the workshop's preparatory activity. Each child received a scenario card and a robot or child card. The child who plays the robot wore the carton box. Children enact the behaviors as described on the cards. The exercise continues until all the children play the role of the robot. At the end of each enactment, the facilitator asks the children to describe what they meant to mean with the behaviors.

After the preparatory activity, children are ready for the main co-design exercise: role-playing with the puppet robot. Each child received a puppet, a scenario poster, cards, and ten wooden blocks. Children played only the role of the puppet-robot, oscillating between the first and second-person perspectives. While the scenario card was the same for all the children, the robot cards were not. Each child received a robot card that they were asked not to share with the other children or read aloud. The main reason was to make the perspective-taking reflection playful: children would "guess" the goal, intention, and feelings of the robot by asking each other the questions on the question card. The activity flow was as follows: First, the facilitator explained that to enact the robot behaviors, children can only use the robot's body, no voice or sounds. Then, she leaves the children to familiarize themselves with the puppet, letting them play freely. After the familiarization, children tried to enact the robot behavior as described on

the robot card. After five minutes, the facilitator asks each child to show to each other their enactment. Children take turns to enact the robot behavior using the puppet and the props. Then, they asked each other the questions on the question card. Children needed to explain the robot behavior they have seen aloud. When children answer all the questions, the child asking the question reads his/her robot card aloud to explain to the children what he tried to enact. The facilitator does not intervene in this process but only asks children's questions about the task and help them with technical issues. When all the children go through this process, the activity ends. The facilitator and researcher thank the children for their participation and ask children for feedback about the workshop.

Evaluation Method and Data Analysis

We audio-video recorded the co-design workshop and analyzed the recordings. To evaluate Exploratory PeerPlay, we examined (i) the outcomes of the role-play activity with the puppet, i.e., the movement generated by the children during puppeteering and (ii) the reflection related to that role-play with the puppet activity, i.e., the behavior explanations children gave on each other design (ii) the critical observations of the researcher and the facilitator. We do not examine the outcomes of role-playing with the body (i.e., the preparatory activity) because it has a propedeutic goal to scaffold children's understanding of perspective-taking. We reflect on this activity through the

Outcomes of the role-play activity with the puppet. To analyze the outcomes of the role-play activity with the puppet, we analyzed the puppeteering movements. To this end, we carried out systematic observations of children's puppeteered movements to quantify and qualify them. Three researchers (two blind to the data collection) developed a coding scheme after familiarizing with the data and some iterations of open and axial coding. We identified three facets of the puppeteered movement's motion that describe them: goal-directed motion, motion parameters, and direction of motion. By goal-directed motion, we mean deliberate movements such as locomotion, rotation of the puppet's body, and elevation of the body of the puppet. We coded the goal-directed motion inductively. Motion parameters are the perceived physical quantity of motion. As we did not track the puppeteered movement, we cannot define the motion parameters with precision and high granularity. However, we can describe and illustrate the perceived motion parameters. We did so deductively. We used the Laban effort framework to describe motion parameters, a widely used framework to describe motion parameters qualitatively. In our work, we apply the Laban framework formalization used in HRI by various authors [355, 204]. Laban breaks down movements into four primary efforts with binary options; we chose four to represent the motion designed by the children. The efforts are: Time, referring to the timing of the motion. Time could be sudden, i.e., the agent

moves with hurried movements and accelerated speech, or sustained, i.e., the agent moves around lingering. Space refers to the precision in a motion trajectory. Space can be direct, i.e., the agent moves towards something or somebody with little deviations in the trajectory, or indirect, i.e., the agent meander and wander around. Weight refers to the perceived force of the motion. Weight can be light, i.e., the agent moves in a lightweight and its body have little force, heavy, i.e., the agent moves with efforts as if it subjected to much gravity. The third coding category was the direction of the motion. We coded whether the motion was directed to a recipient (i.e., one of the two children on the scenario posters) or objects (i.e., the blocks given to the children); whether the puppet robot was directed away from the recipients or the objects. We coded the directions inductively. Two annotators blind to the data collection carried out the annotations in ELAN, a software to manually annotate audio and video ¹. The annotators reached a substantial to very high agreement: goal directed motion ($d = 0.864$ $p = .001$), motion parameters ($d = 0.781$ $p = .000$), direction of the motion ($d = 0.901$ $p = .000$). Table 16 reports the coding scheme of the outcomes of role-play.

To analyze each other's behavior explanation, we transcribed the children's explanations and carried out a deductive thematic analysis of the answers. The theory of folks explanation of behaviors described in our conceptual framework (See Chapter 2 and the background section in this chapter) provided the main themes to focus on. The resulting themes are as follows: (i) Prosocial/Antisocial/Passive interpretation of the behavior, refers to how the children have interpreted the underlying intention of the robot; (ii) Alternative interpretation of the robot behavior, refer interpretations that are not related to the prosocial, antisocial, passive intentions (iv) Psychological explanation refers to children explaining the robot behavior as caused by mental states (v) Causal explanation refers to children explaining the robot behavior as caused by natural states (vi) Social Qualities Attribution refers to children explaining the robot behavior having social qualities. Table 17 reports the themes, the definition of each theme, and examples from the corpus of children's explanations. Two researchers, one native Dutch speaker, carried out the thematic analysis. The annotators reached a substantial agreement: prosocial/antisocial/passive interpretation ($d = 0.794$ $p = .001$) psychological explanation ($d = 0.831$ $p = .001$), causal explanation ($d = 0.821$ $p = .001$), social qualities attribution ($d = 0.859$ $p = .000$).

Finally, we coded and counted whether the children interpreted the puppeteered movement's goal as the card indicated. We counted the instances of correct/incorrect interpretation.

¹ <https://archive.mpi.nl/tla/elan>

Codebook Co-design Behaviors	
Code	Definition
Goal-directed Behaviors:	A deliberate motion of the puppet robot.
Locomotion	Locomotion means to move in the space in trajectories.
Rotation	Rotation means rotating the body of the puppet along the x or y-axis.
Elevation	Elevation means elevating the body of the puppet, jumping wiggling.
Motion Parameters:	
Time Sustained	Refers to the Laban Effort Framework. Time, the timing of the motion. Weight perceived force of the motion. Space precision in a motion trajectory.
Time Sudden	
Weight light	
Weight heavy	
Space Direct	
Space Indirect	
Direction:	
Towards recipients	When a child grasp an object from another, while the other tries to stop him/her
Towards objects	
Away recipients	
Away objects	

Table 16: The table details the coding scheme of the to analyze the outcomes of the role-play activity with the puppet. We analyze the movements children made while puppeteering taking into account goal-direct behaviors, motion parameters and trajectory.

Deductive Thematic Analysis		
Deductive Theme	Definition	Examples
Intention: Prosocial/Antisocial/Passive	Children interpreted the intention of the designed behavior as prosocial, antisocial, and passive.	<i>"He wanted to help them find all the batteries"</i> <i>"Because he finds the other two (Jip and Femke) very unkind (and therefore did not want to help)"</i> <i>"Because he didn't want to help"</i> <i>"Because it was doing some sorting by itself"</i>
	Prosocial descriptions include helping, collaborating. hindering, creating obstacles. Passive descriptions include sorting without caring about the situation.	
Alternative intention	Children interpreted the intention of the designed behavior in unexpected ways.	<i>"I think he thought it was boring because he had to do it very carefully"</i> <i>"I think he wanted to get rid of the batteries because they weren't good for Jip and Femke"</i> <i>"I think it is doing it they don't get poisoned"</i> <i>"He delivered it very neatly, he did not cause things to break."</i>
Psychological explanation	Children provided explanations related to psychological states	<i>"He's pissed off - they couldn't give him any special oil because he didn't have enough"</i> <i>"He didn't really feel like searching anymore, just started playing with the batteries or something"</i> <i>"Because he liked collecting the batteries and then he gave them to Jip and Femke"</i>
Causal Explanation	Children provided explanations for the robot behavior related to natural causes or factual causes	<i>"Because otherwise the spaceship will no longer work and we cannot leave"</i> <i>"It does what it does because Mars is a difficult place"</i> <i>"It's a bad boy"</i>
Attribution of Social Qualities	Children attributed social qualities to the robot to explain its behaviors	<i>"It is annoyed"</i> <i>"He is very nice and friendly"</i> <i>"He does not care"</i>

Table 17: The table details the themes used to analyze children's explanations of their robot behavior designs.

Co-designed Movements			
Movements:	Prosocial Intention	Antisocial Intention	Passive Intention
Actions: goal-directed motion	Locomotion: Pushing objects Rotation: moving on x and y axis Elevation: jumping, wiggling	Locomotion: pushing objects, scattering objects, stepping onto objects Rotation: moving on x- and y-axis Elevation: jumping, wiggling	Locomotion: pushing objects, sorting objects Rotation: moving on x- and y-axis Elevation: -
Laban Efforts: motion parameters	Weight: light Space: indirect Time: sustained	Weight: heavy Space: direct Time: sudden	Weight: light Space: indirect and direct Time: sustained
Direction: direction of motion	Towards recipients Towards objects	Away from recipients Towards recipients Towards objects	Away from recipients Towards recipients Towards objects Away from objects

Table 18: The table summarizes the actions (goal-directed motion), the Laban Efforts (motion parameters), and direction, (direction of motion) children have used to design prosocial, antisocial, passive intentions of a robthing. In bold, the actions, Laban Efforts, and trajectories that were observed with more frequency in the corpus of co-designed behaviors.

Lastly, we provide a narrative account of researchers' observation of the workshop. We account for what worked well or not in terms of facilitation, organization and children's engagement in the workshop.

5.2.2 Findings

In this section, we report the findings of the Exploratory PeerPlay Workshop: We discuss the design outcomes from the role-play with a puppet reporting counts in the form of percentage; These findings are the children's movements to enact the robot behaviors. Then, we discuss the findings from the thematic analysis of children's reflections of the role-play with a puppet exercise. We report the main themes and quotes substantiating the themes. Additionally, we report whether the children interpreted the movement's goal as the card given to them indicated. Finally, we critically examine the observations of the researcher and facilitator.

Co-design Outcomes: Children's Movements to Enact a Robot's Behavior

To co-design a robot's prosocial intention, that is, to give a battery to another child, 91.6 % of the children used movements that embody the robot puppet's locomotion to push the wooden blocks. A minority of the children (5.4 %) used rotations of the robot puppet or jumping/wiggling (3 %) to render the behavior. In terms of motion parameters, most children (78.9 %) applied a combination of light weight, indirect space, and sustained time. The rest of the children applied variable motion parameters; no other trends emerged from the annotations. In terms of direction, children used two trajectories towards the object (91%) and the recipients (8%).

To co-design and antisocial intention of a robot, that is to take away the battery from another child, the majority (83.5 %) of the children used the locomotion of the robot puppet to push the wooden blocks away. 5 %

of the children used motion that scatters objects, and 8% of the children used stepping onto objects. 1,5 % of the children used rotation, and 2% of the children elevation movements like jumping and wiggling. In terms of motion parameters, most children (87,3%) applied a combination of heavy weight, direct space, and sudden time. 11% of the children involved a variety of heavy weight, indirect space, and sudden time. 1,7% of children used other combinations without a relevant pattern emerging. In terms of direction, most children (79,9%) used a trajectory away from recipients in combination with a direction towards objects. 19.1% used a trajectory towards objects, 1% of the children towards recipients.

To co-design a passive intention of a robot, that is, to sort batteries independently, 86.7 % of the children used the robot puppet's locomotion to push the wooden blocks. A minority of the children (13,3 %) used rotations of the robot puppet. In terms of motion parameters, most children (68,9 %) applied a combination of lightweight, indirect space, and sustained time. The rest of the children (31,1%) applied direct space rather than indirect. In terms of trajectories, children used two directions towards the recipient (51%) and away from the objects (49%). Table 18 summarizes the actions (goal-directed motion), the Laban Efforts (motion parameters), and direction, (direction of motion) children have used to design prosocial, antisocial, passive intentions of a robothing. In bold, the actions, Laban Efforts, and trajectories that were observed with more frequency in the corpus of co-designed behaviors.

Children Reflection: Thematic Analysis

Prosocial/Antisocial/Passive Interpretation. Children who watched another child enact the “giving batteries” behavior with the robot puppet interpreted the movements children chose to enact the behavior as prosocial. Hence, the chosen movements communicated the intention that was intended. However, we observe that in some instances, 12% of the time, children attribute alternative intentions. The descriptions of alternative intentions vary considerably. Some reflections were not pertinent to a specific intention. Still, more to a mental state attribution, for instance, P10 (Participant 10) states *“I think he thought it was boring because he had to do it very carefully”*. Other explanations have some connection to a prosocial stance. For example, P3 explains *“He delivered it very neatly, he did not cause things to break.”* This explanation underlies neither semantically nor latent a prosocial behavior like helping or sharing. However, it has some connection with the idea that the robot is paying attention to not harming the children.

Children found it hard to interpret the taking away objects behavior, i.e., the behavior meant to be antisocial, and the sorting independently behavior, i.e., the behavior intended to be passive. The majority of children attributed an antisocial intention of taking away object behavior. Still, sometimes they interpret it as a passive intention or provide alternative meanings and explanations that could also be seen as prosocial. For example, P5 explained:

"I think he wanted to get rid of the batteries because they weren't good for Jip and Femke" Surprisingly, the majority of children attributed to the sorting behavior an antisocial intention. They described the sorting behavior, meant to be passive, as a negative. For example, P6 states: *"I think he did not want to help, it was doing whatever it wanted"*.

Psychological and Casual explanation. Children blend psychological explanations and causal explanations of the behavior of the robot puppet. The majority of children's explanations are psychological, but many are causal explanations. Examples of psychological explanations are (P1) *"because he wanted to make it fair that they both had the same amount of batteries"*. In contrast, examples of causal explanations are (P4) *"Because otherwise the spaceship will not longer work and we cannot leave"*. It is interesting to notice that explanations, both psychological and casual, are quite intricate. Children appear to expand narratives on their own to contextualize the psychological and causal explanations. For example, P7 explained a back story about the robot's reason to behave such as: *"that he wanted to prove that he was also good at counting and that he knew how many batteries there were and then he knew he had found all the batteries"*, or P5 that *"He wanted to distribute it fairly and that he wanted to keep it fair"*.

Attribution of Social Qualities. Interestingly, children's psychological explanations and the explanation of the possible feeling of robot contain many social qualities attributions. Social attribution variability is high; hence, it is difficult to describe a dominant trend or patterns. However, analyzing the social qualities attribution per robot intention, the behavior designed to communicate a prosocial intention is often portrayed with positive social attributes. For instance, (P1) *"He is very nice and friendly"*, or P5 *"He felt proud and helpful for having proven that he could count well and found all the batteries. He is collaborative"*. Conversely, children attribute negative social qualities to behaviors underlying antisocial intentions. For example, (P8) *"It could also be that he is angry and that he sends them away and throws out all the batteries."* However, children attribute also positive qualities to robot behavior underlying an antisocial intention. For example P12 *"He feels enthusiastic - he hid the stones, he wanted to get rid of it so he wanted to do it. He is happy, and he is nice"*. As far as the passive intentions are concerned, children attribute a plethora of social qualities, with variability. No trend arises from the corpus of answers. What we find interesting is that children attributed negative social qualities to a passive robot behavior. For example, P15 describes *"the puppet is happy because he couldn't help (he likes to make it harder), he is a mean robot"*, or *"the robot says I'm going away, I don't feel like it anymore"*. But also, positive social qualities such as *"The robot is playful - it was jumping and playing"*. To make sense of this variability, we assess whether there is a relation between goal-directed motion, motion parameters, or trajectory of the robot and social qualities' attribution. Along with describing the intention of the robothing, children attributed affective states and social attributes to various movements. For example, in behaviors

rendered with motion parameters associated with an antisocial intention, children attributed negative social qualities like being “bossy”, a “mean”, “angry”. Conversely, children attribute positive social qualities like “happy”, “friendly”, “collaborative” to behavior with motion parameters used more frequently to design a prosocial intention. No particular trend has been found for motion parameters associated with passive intention.

Interpretation of the Card

Children interpreted the giving batteries behavior correctly 96% . However, children found it hard to interpret the taking away objects behavior and the sorting independently behavior. Children interpreted this behavior as taking away objects correctly only 47% while 53% of the time the interpret the behavior differently, for instance as a stealing or hiding object behavior. Children interpreted this behavior as taking away objects correctly only 47% while 53% of the time the interpret the behavior differently, for instance as a stealing or hiding object behavior.

Insights from the Facilitation and Observations of the Workshop Process

We gather observations about the workshop facilitation, observations about children’s engagement in the activities, and observations about the role-play with the body activity. The facilitator balanced the necessary scaffolding with detachment, leaving the children to their activities. We noticed that children needed more support in the role-play with the body activity, while role-play with the puppet was mainly self-managed. At the same time, we saw that it could be necessary to mediate the group dynamics arising in the co-design groups.

Children engaged enthusiastically in the workshop. We considered a child as engaged when he/she would participate in the exercise without being directed to do so. Children paid attention to the tasks and did not digress. All the children collaborated to participate in co-design activities on top of the emerging group dynamics. However, children found role-play with the body exercise to be more challenging. Children did not require much support from the facilitator during role-play with the puppet. Whereas the facilitator prompted the children more during the role-play with the body. While our pilot showed us that role-play with the body was propedeutic for children’s understanding of perspective-taking in the workshop, we noticed that it did not affect these sessions in the same way. Half of the children expressed difficulties putting themselves in the robot’s shoes by role-playing with their body and wearing the robot card box. They did not know how to move or what to do despite the description of the card’s behaviors.

5.2.3 Discussion

This workshop's goal was to evaluate the potential outcomes of Exploratory PeerPlay both in terms of co-design outcomes (i.e., enactment of behaviors resulting in potential "designs") and in terms of reflection about the agency of a robot in context. This section discusses how Exploratory Peer-Play provides insights into how children would design a robot's movements to communicate a specific goal, intention, and social quality. In our discussion, we scrutinize whether the method stimulates children to express how they interpret and explain a particular non-verbal behavior of a robot, which we know is essential for children to elaborate on a robot's agency. Finally, we elaborate on design implications and limitations.

What Co-design Outcomes Children can Design Through Exploratory PeerPlay?

Children puppeteered the behavior given to them through cards manipulating the body of the puppet. The resulting movements are low-fidelity prototypes of non-verbal robot behavior. Therefore, exploratory Peer-Play yielded a rich corpus of low-fidelity prototypes of non-verbal robot behaviors through puppeteering of the behaviors. We have identified three categories of motion elements that children used to "design" the behaviors: goal-directed motion, motion parameters, and direction of the motion. We have noticed that many of these motion elements are recurrent. We summarize the insights from the co-design outcome below.

- Children use a robot's locomotion as the main means of communication: When puppeteering a robot puppet behavior, children predominantly use the robot locomotion to enact the goal-directed behaviors. When reflecting on their designs, children describe the locomotion as giving/distributing objects towards or away from children or just sorting. Children imbued the robot puppet given to them with prosocial, antisocial, and passive intentions, thereby "designing" the behaviors of the robothing. In their enactment, children move the robot puppet back and forth using the puppet's base as if it was a shovel to push objects around the space and towards children in the fictional scenario. Children use other movements like jumping and wiggling and rotation of the base, but they appear not to be as common as locomotion is.
- Children layer motion parameters onto the locomotion to reinforce or nuance a robot puppet intention: We show that children use Laban efforts such as motion parameters of space and weight to stylize the motion. A parameter of space in the Laban System indicates whether the motion has a direct trajectory or an indirect trajectory. Children used direct and indirect space trajectory profusely. In particular, we noticed that when children design a robot's prosocial intention, they often use indirect trajectories meandering in the space. When children

develop an antisocial intention, they make more direct trajectories, shaping the motion in straight or broken lines. Children also use a combination of direct and indirect space trajectories, but with low frequency. A parameter of weight defines how a robot uses its body weight when moving. A strong weight indicates that motion is delivered with force and power, while a light weight shows that motion is delivered delicately. Children mainly use a light weight, but they often use a strong weight to enact antisocial behavior. Again, children use other motion parameters, such as time (a parameter of speed in the Laban system), but not as frequently as weight and space.

- Children use locomotion to make clear the recipient and objects of a robot puppet behavior: The behaviors children design aim at the recipient and the object of the communication act: children direct the actions of a robothing to the people the robothing is communicating with (recipients) and towards the objects of the communication. When children enact the locomotion, they make clear trajectories: locomotion is directed towards or away from recipients or objects. When children design for a prosocial intention, they appear to direct the locomotion mainly towards recipients and objects, while for an antisocial intention mainly away from recipients.

Therefore, Exploratory PeerPlay in the form of role-playing with a puppet provides children with an exercise to express their tacit and latent knowledge about a robot's behavior to communicate particular intentions. All the children participating in the workshop were engaged in enacting the behaviors and produced co-design outcomes. The co-design outcomes provided us, the researchers and designers, with rich insights into children's way to enact non-verbal robot behaviors. Designers could readily use the insights to develop a robot's behavior. Still, they should translate the movements into a robot's motion with all the constraints derived by a robot's form, function, and technology. The design outcomes from this activity are in the form of motion elements for our specific scenario. Still, we anticipate that could include vocal or verbal modalities as well for other scenarios.

We reflect on how the two exercises of PeerPlay contributed to the co-design outcomes. While we do not analyze the role-play with the body because it is a preparatory activity rather than a productive activity. However, we observe that this activity should be reconsidered as it might be hard for children as a propedeutic exercise to activate them. One of the workshop's insights is that puppeteering with a robot putter and taking a second-person perspective, and role-play in a tangible scenario with a proxy to better children express themselves. It produces a rich set of non-verbal behavior prototypes that could be further analyzed by designers. In light of the researcher and the facilitator's observations, we suggest that role-playing with the body should be revised or limited to a bodystorming exercise to

help children make a connection between their embodied experience and their thoughts.

5.2.4 *What Reflections Exploratory PeerPlay Yield in Children?*

Exploratory PeerPlay, particularly role-play with a puppet, appears to enable children to reflect on a robot's intention, social qualities, and explanation of behavior. Children easily discuss aspects of a robot's agency through a playful reflection after a pretend play exercise such as puppeteering an imaginary robot's behavior. We have gathered rich insights about how children interpret the movements that together make a robot behavior. The exercises have helped children verbalize how they make sense of a behavior, how they perceive the intention and social qualities of a robot from its movements in context. Children found it easy to answer the questions given to them and elaborate their answers providing details and backstories for the robot puppet. All in all, alternating first and second person perspective while enacting behaviors appear to facilitate children in expressing their ways of making sense of robot behavior.

Children's reflections are quite variable and remain difficult to discern, though. Interestingly, specific actions are associated with prosocial, antisocial, and passive intentions as well as positive or negative social qualities. For instance, locomoting and pushing objects towards other (imaginary) children is often deemed prosocial and considerate. In their answers, children rarely challenge the robot's autonomy, and they describe the robot's behavior as deliberate. In line with the literature, [125, 240], we find that children, when discussing the explanation for an action, the first step to the understanding agency, blend psychological to casual explanations. This insight is valuable because it can help designers to think about the scenarios of an interaction carefully as they are significant sources of agency's understanding for children. We have noticed that children like to expand these explanations' narratives, almost building a whole world around the imaginary robot. With this insight in mind, designers could try to involve children in designing scenarios and "characters" of robots. By engaging in co-pretense exercises, children and designers could actively work to establish a responsible illusion of life that does not deceive but leverage children's tendency to build stories around the illusion of life.

Another exciting insight is that children build a "*character*" for a robot to explain its behavior, attributing social qualities to it to motivate specific actions. A robot is deemed angry when scattering objects around, for example. We even find some indications that motion elements such as the motion parameters are sometimes associated with positive and negative social attributes. Children often use the term "happy" for a light, indirect, and sustained locomotion. Other times, they associate bossiness with heavy, direct, and sudden locomotion. The answer's variability makes it challenging to conclude on children's character building tendency. Therefore, we

interpret these insights cautiously as a definite pattern in the children's responses is missing. However, we believe that these insights are relevant and should be explored further.

Implications for cHRI

Exploratory PeerPlay yields low-fidelity prototypes of behaviors and reflections that cHRI design could use to start the design process. The low-fidelity prototype could provide cHRI researchers with several motion elements to use as building blocks of a robot's behaviors. The reflections could support the decision making in the design process, motivating design choices with children reflections. The Exploratory PeerPlay activity is low-fidelity, low-cost, and portable; thus it could be easily implemented to explore robot behavior design.

However, there are open questions regarding how to translate the knowledge gathered from the Exploratory PeerPlay workshop into design considerations. It is difficult to associate the motion elements children enact with the reflections they make; at least, it is difficult to do this *a posteriori*. In this operationalization of the Exploratory PeerPlay activity, we decided to leave the reflection only to children who experience the behavior rather than the children designer himself/herself. In retrospect, asking the child who made the "design" to explain the action rather than reading the behavior he/she was assigned with could give more insights about how children associate specific movements with intentions, reasons to act and social qualities.

Moreover, cHRI designers might find it hard to translate low-fidelity behaviors described qualitatively through annotations into discrete robot behaviors to implement in a robot platform. Differently from other scholars [7, 355], we decided to keep children's experience as low-fidelity as possible to avoid technical issues and to enable children to have flexible materials. A low-fi solution such as endowing puppets with pencils to draw the motion while puppeteering like in [7] might work well if the focus is mainly on designing the locomotion of a robot. However, such techniques might lower the behaviors' variability and leave less freedom to the children's expressions.

Thus, further iteration of Exploratory PeerPlay should include evaluations with cHRI designers to assess how the co-design outcomes could be integrated into the cHRI design process of a robot's behavior.

Lastly, we believe that PeerPlay could support children and designers to collaborate in suspending the disbelief in fruitful ways. cHRI designers could also use the method to inform the narrative and scenarios in which interaction with a robot unfolds. Given that children tend to expand their explanation of enacted behaviors to a story related to the robot's intention and social qualities, designers could engage in a responsible co-pretense that does not cause deception.

Limitations

Our workshop has some limitations. The way we operationalize Exploratory PeerPlay has some limitations. We confine role-play with the body as a propedeutic activity; thus, we do not gather systematic insights about the effectiveness of starting our workshop by stepping into the robot's shoes. We learn from observations of the exercise that it is harder for children to carry-out role-play with the body than with the puppet. Future implementations of Exploratory PeerPlay should closely examine the contribution of role-playing with the body to assess whether it impacts children's co-design outcomes.

To facilitate Exploratory PeerPlay elicitation, we have provided the children with scenarios that describe both the context of interaction and their behavior. We deemed this a good way to structure the Exploratory PeerPlay activity, but it might have been too suggestive and perspective for children. In future iterations, we could consider leaving out the robot cards and letting children develop their behaviors in a given situation. Or even to let them structure the complete scenario. However, it is essential to assess whether a more open-ended activity will work with children in middle-childhood or if more structure is needed to facilitate co-design.

This workshop does not explore multiple scenarios and applications of Exploratory PeerPlay. Hence, the workshops' findings are not applicable to the cHRI field at large but only provide insights for designers who work on robot's non-verbal behaviors. Moreover, we have evaluated Exploratory PeerPlay with a specific sample of children and a limited cultural context. To better understand the applicability of Exploratory PeerPlay, we should run a workshop in different contexts and cultures.

Lastly, we evaluated PeerPlay in a workshop with a small number of children. The insights we gathered are relevant to understand the method's applicability but cannot be considered a full-fledged validation. Much of the literature's co-design methods and techniques are not extensively tested in various settings and with multiple children [102]. It is costly and hard to run co-design studies with children, and the co-design epistemology is open to fluid ways to intend validity [102]. However, we are aware that PeerPlay should be tested in various settings and with multiple children to consider the method as a valid way to co-design behaviors with children.

5.2.5 Exploratory PeerPlay Workshop: Conclusions

In the Exploratory PeerPlay workshop, children could express their tacit knowledge about how a robot should behave in collaborative play with children. The Exploratory PeerPlay activities engaged children in enacting an imaginary robot in a fictional scenario. All the participants were able to design behaviors and reflect upon them.

By enacting the robot's behavior, children gave insights on the actions and motion elements that communicate a specific intention. The co-design outcomes are insightful for cHRI designers, providing a set of motion elements children attribute to a robot's particular intentions and social attributes that children see as a deliberate agent.

Additionally, from children's reflections of each other robothing's behavior design, we learned that children imbue the robothing with prosocial, antisocial, and passive intentions and render a sort of '*character*' for each of the robothing behaviors. Along with describing the robot's intent, children attributed affective states and social qualities to various movements. However, the variability of attributions is too high to identify well-defined characters. We attribute this characterization to the motion parameters, but we are cautious in interpreting these insights considering the high variability in the responses.

Exploratory Peer-Play has some limitations, mainly due to its operationalization. Still, we argue that he provided us with rich insights about how children make sense of robot behaviors, which would have been hard to gather only with user testing activities. We anticipate that Exploratory PeerPlay needs to be tested in more scenarios, context, and culture. It should be evaluated with roboticists to assess its generative potential and what is possible to do with the co-design outcomes.

The workshop was not meant to validate the PeerPlay method but assess what co-design outcomes and reflections on agency children can do through Exploratory PeerPlay. We believe that the workshop findings give a preliminary indication that Exploratory PeerPlay could support the generative effort of the early design process in cHRI by bridging the knowledge gap between designers and children and providing a window into children sense-making of robot's behavior and ultimately of a robot's agency.

5.3 WORKSHOP 2: BEHAVIOR AUTHORIZING PEERPLAY

In this section, we present a pilot to operationalize Behavior Authoring and a workshop to evaluate our operationalization. We sought to understand whether the activity supports children in authoring a robot's behavior in an existing platform and reflecting upon it. Notably, we were interested in understanding whether our operationalization with a tangible proxy that controls a robot platform, thereby authoring behaviors, is usable by children and enable children reflections of a robot's agency in context.

5.3.1 *Pilot to Define the Behavior Authoring Operationalization*

In a pilot study run in collaboration with students of the University of Twente, we sought to understand how to operationalize Behavior Authoring PeerPlay. To this end, we compared two interaction paradigms that are dom-

Behavior Authoring Operationalizations

Figure 41: In the figure, on the left the tangible behavior authoring operationalization featuring the physical device bearing similarities with the robot platform. On the right, the GUI based operationalization.

inant in Behavior Authoring: a graphical user interface based on a digital representation of a robot and a tangible interface focusing on kinesthetic control. Both prototypes represent a way to puppeteer (i.e., choreograph) the motion of a robot.

Our digital interface is a tablet GUI-based interface that maps the motion of a robot icon to a robot's platform motion, see Figure 41. Children drag the robot's icon in the GUI to make the robot platform move. It is a way to choreograph the behaviors. Our tangible interface is a physical device, bearing similarity in appearance with a robot platform. The physical device work as a proxy to control the robot platform. It is equipped with sensors (speed, rotation, tilt angle) that sense the puppeteered motion, and it mirrors it to control the robot. There is a direct mapping between the small controller and the big robot resulting in navigation on the z-plane with rotation and forward/backward movement. A rotary encoder is connected to a small wheel in contact with the floor; this senses back and forwards movement speed. The controller's rotation is measured by a compass sensor, which is part of the same inertial measurement unit (IMU) as the accelerometer. A battery pack of 4 AA batteries supplies for all 5V components. See Figure 41.

In an informal evaluation (20 children between 9 and 11 years old $m = 9.55, sd = 0.55$), we found that the tangible prototype provided a more coherent mapping to externalize and embody children's enactment of robot's behavior. Hence, we decided to continue exploring a kinaesthetic interaction paradigm for behavior authoring.

5.3.2 *Workshop Method*

We organized a workshop to evaluate Behavior Authoring PeerPlay with children. The workshop's goal was twofold: (i) examining whether the tangible interface for Behavior Authoring enable children to author given behaviors by making the robot imitate the behavior of a tangible proxy (ii) examining whether behavior authoring through kinesthetic imitation enable children's reflections on the narrative laying behind the behaviors, i.e., the sequence of intentional behaviors of the robot, which is connected to the understanding of agency in context (See background)

Participants

The workshop was conducted with 85 participants recruited among two classes from international elementary schools in Manchester (UK), and Hengelo (The Netherlands), where the language of instruction is English. Their age ranged between 7 and 12 years ($m = 9.23$, $sd = .95$, Median = 10); 81% of the participants had seen a robot in real life before and 55.6% reported to have played at least once with a robot.

Ethics

The Ethical Committee of the University of Twente approved the study. The participants' legal tutors (e.g., parents, relatives) and teachers received and signed an informed consent form before the workshop. All children participants gave verbal consent to participation. At the end of the study, children were debriefed regarding the workshop's scope and the robot's autonomy.

Behavior Authoring Peerplay: Operationalization and Scenario

In light of the pilot's insights, we focus on Behavior Authoring through a tangible proxy that we called Brobotino, that controls a robot platform, in our case, a Festo Robotino platform with a Styrofoam shell (used in Study 2, Chapter 4). In Behavior Authoring, children engage in two playful exercises: (i) Children author a given sequence of non-verbal behaviors (i.e., locomotion) in a narrative context about help-giving through tangible manipulation of Brobotino. By controlling Brobotino, children make the Festo Robotino robot mirroring Brobotino's Behavior. (ii) Children observe the behavior design and describe what the robot does and its intentions in context.

We developed an interaction scenario in which to situate the interaction with the robot. The scenario focuses on a collaborative play activity between a robot and a child. The robot shares several objects which the child needs to conclude a sorting task. Children receive a general description of the

Figure 42: In the figure, the Behavior Authoring operationalization in the workshop.

scenario on a card (similar to Exploratory PeerPlay). The description does not specify the robot’s intention, but only the robot’s action.

Materials, Setup and Protocol

To facilitate children’s enactment and reflection, we prepared three materials: the Brobotino, the tangible interface functioning as a proxy to author behavior, a scenario card, and some carton boxes serving as objects to sort. The scenario card described the following narratives: Narrative 1: *“Festo Robotino is playing a sorting game next to a child. The robot pushes objects towards the child and approaches him/her. To make it do that, you can use a mini-version of the robot, called Brobotino”*. Narrative 2: *“Festo Robotino is playing a sorting game next to a child. The robot pushes objects away from the child. To make it do that, you can use a mini-version of the robot, called Brobotino”*.

The workshop took place in an interactive experience for children organized in conjunction with an international conference and at the University of Twente. In both cases, children worked in a rectangular area dedicated to the workshop. One child sat on one side of the rectangular the other on the other side. Due to the ethical restrictions, we were unable to video-record the interaction.

A researcher facilitated the workshop. The researcher welcomed dyads of children in the workshop area. After a brief familiarization with the robot platform and warm-up activity, the researcher explained the workshop structure and gave each child one narrative, either narrative one or narrative two. In turns, children role-played their scenario by controlling the Brobotino proxy, thereby kinematic imitation with the Festo Robotino. While one child was role-playing with Brobotino, the other observed Festo Robotino’s behaviors to make sense of the narrative. After that, children reflect on

ROLE-PLAY BY ENABLING KINEAESTETIC IMITATION

OBSERVING TO MAKE SENSE OF THE NARRATIVE

Figure 43: In the figure, children participating in the behavior authoring workshop. On the left, a child co-designer role-play, enabled by kinaesthetic imitation. On the right, a child observing the role-play and making sense of the narrative.

the actions, explaining to each other the narrative they perceived and the robot's intentions in the robot. After the reflection, the workshop ends. Each workshop session lasted from 10 to 15 minutes in total.

Evaluation Method and Data Analysis

To evaluate the Behavior Authoring PeerPlay activity, we use qualitative methods, namely observations and inductive thematic analysis. We observed whether: (i) The accuracy and degree of completeness with which users achieve the Behavior Authoring; (ii) the comfort in using the tangible proxy (iii) whether children understand each other designs and elaborate on a robot's intention.

A researcher observed the Behavior Authoring activity and assessed the behavior authoring's accuracy and completeness through observations. We evaluated whether children could completely enact the scenario (yes/no) and whether the scenario is accurate (accurate/moderately accurate/inaccurate). We report percentages. We assess the comfort in using the tangible proxy by asking the children a question ex-post the behavior authors activity: *How comfortable is it to use Brobotino? Please explain why..* We note down the answers, and we transcribe them. We report qualitative insights from children's responses to the question. We assess whether children understood each other design and elaborated on the robot's intention in the scenario by noting down the narrative description. We assess whether children give an interpretation in line with the given scenario, the correct interpretations or if they do not give an interpretation in line with the given scenario, incorrect interpretations.

We carry out inductive thematic analysis, as per Clarke and Braun methodology, [60] on the narrative descriptions given by the children. After familiarizing with the transcribed data, and iterative sessions of latent coding of the data, we identified three themes: (i) Relationship between the two robots (ii) Psychological explanations (iii) Robot social attributes. The theme relationship between the two robots concerns the way children intended the connection between the robot proxy and the real robot platform. The theme psychological explanation concerns how children described the reason for the robot to interact as a function of internal states, like moods. The robot social attributes theme concerns the children's description of the robot's social attributes (i.e., helpfulness) as a reason to interact.

5.3.3 Findings

In this section, we report the qualitative findings from the Behavior Authoring Workshop. We report the findings per dimensions providing percentages and quotations from children's answers or reflections where applicable.

Accuracy and Degree of Completeness with which users achieve the Behavior Authoring

89% of the children were not able to enact the scenario; ultimately, only 11 % of the children completed the scenario described on the card. Children were not able to enact the behavior described in the scenario. The children who could not enact the scenario completely did inaccurate 50% and moderately accurate 50% scenarios. Of the 11% of children who completed the scenario, only 20% did it accurately, sequencing behaviors while 10% did it moderately accurately. 70% of the children who completed the scenario did it inaccurately.

Comfort in Using the Tangible Proxy

Most of the children find a tangible proxy uncomfortable. 78% of the children describe Brobotino as hard to use and not comfortable. Children explain that Brobotino is "difficult to use" (P49), "hard to rotate" (P32). They explain that they consider Brobotino uncomfortable because of mapping delays "slow in making the other robot move" (P66). Children found it hard to understand the mirrored mapping "I do not understand why they move as if they were in a mirror" (P72), for ergonomics reasons "too big for my hand" (P3). 13% of the children describe Brobotino as moderately comfortable, but with poor usability, "okay to use but sometimes it is difficult to control" (P45). Only 9% of the children consider Brobotino comfortable to use. They explain that for them, Brobotino is intuitive, "I could make sense of the way it works

straightaway" (P22) and fun to use *"I think it is comfortable because it is fun"* (P80).

Children Reflections

Children found it hard to interpret the robot behavior and the narrative the behavior in embedded in. 75% of the children provided an incorrect understanding of the narrative, while 25% of the children give a correct interpretation of the narrative.

Relationship between the two robots theme. We identify a recurrent theme in children's descriptions. Children appear to consider the proxy and the robot platform as interacting with each other rather than the other's controller. For example, the children describe Brobotino as *"distracting the other robot from its actions"* (P22) or Brobotino as *"trying to motivate the other robot to move"* (P41). Another interpretation line is that Brobotino and the robot are competing for resources, for instance *"Scaring away the big robot so Brobotino can play alone with the boxes"* (P13).

Psychological explanations. Children attribute to the robot's moods and desires that they consider to be the reason for the robot to act deliberately in the scenario. Hence, they provide psychological explanations. For example, children expanded on the reason why the robot is sorting. Children describe the reason for sorting as a function of moods or desires, for example *"The robot is bored"* (P32) or *"The robot likes to sort and wants all the boxes"* (P74). However, children do not converge on a specific explanation of the robot's behavior.

Robot social attributes. Children attribute various social characteristics to the robot and often to the proxy too. Children consider the proxy as a helpful friend who helps the robot. For instance, *"The tiny robot wants to help the big one move in the area because the big one is clumsy and cannot move well"* (P51). Or another example, *"The robot is stubborn; it does not want to move"*.

5.3.4 *Discussion*

In workshop 2, we test our second activity in PeerPlay, Behavior Authoring. In particular, we test whether the tangible interface for Behavior Authoring enables children to author robot behaviors and whether behavior authoring through kinesthetic imitation enables children's reflections on the narrative laying behind the behaviors, i.e., the sequence of intentional behaviors of the robot. We focus on a playful sorting scenario in which children are invited to design a robot's non-verbal prosocial and antisocial behavior. In this section, we critically discuss the findings and provide implications for cHRI.

Does Behavior Authoring Enable Children's to Co-design Behaviors?

Findings show that children find it hard to author behavior with a tangible proxy. Even though our pilot results show that children find it easier to choreograph behaviors with a tangible interface rather than a GUI, only a minority of the children could author the behaviors in the scenario given to them. They found it hard to do it accurately, too. They describe many usability and learnability issues. In particular, it is difficult for them to map Brobotino's movements to the Festo Robotino's ones. We could attribute these findings to technical constraints and low mapping between the proxy and the robot. We did carry out the workshops *in-the-wild* to guarantee a higher ecological validity and put the children at ease. However, the setting might have impaired the stability of the mapping between the proxy and the robot. While children could co-design the behaviors in the robot, the outcomes were of low quality. Children did not find the tangible proxy to control and author the robot behavior comfortable. These findings are in contrast with the literature and with our pilot's result. On top of the possible malfunctions, we believe that the decision to design the proxy as a one-on-one representation of the robot might have impaired children understanding of the mapping between the two. A different form of the proxy could have helped the children to have a steadier control of the proxy. Another explanation is that real-time mirroring is too complicated for children in middle childhood.

Does Behavior Authoring Enable Children's to Reflect on a Robot's Agency in an Interaction?

Considering the technical and comprehension challenges, children find it hard to take perspective on each other design and interpret the authored behaviors. Children found it hard to understand the narrative and explain the reason behind the robot's behavior. Interestingly, the activity supported some reasoning about the relationship between the proxy and the robots, providing insights about how children make sense of the activity itself. Even though children are presented with a practical task, controlling one robot with a look-alike proxy, they build a narrative behind the two robots to make sense that one influences the other. Again, this indicates how casual and psychological explanations intertwine in children and how we should consider them, even when designing co-design activities. We observe that Brobotino is not seen as a proxy, rather as an actor in the scenario, establishing an interaction with the Festo Robotino. Both are endowed with social attributes, moods, and desires. Both are intended as deliberate agents, with one controlling the other. We infer that children dis-entangle Brobotino from the actual robot, which the proxy control. Children appear to take the perspective of Brobotino and the one of Festo Brobotino rather than focusing on the Festo Robotino platform. These insights connect with Ackermann's transaction model [2] and show that the activity supports

children in reasoning about a robot's agency. However, we need to be aware of children's tendency to personify the proxy and re-design the activity around this phenomenon.

Implications for Future Work and cHRI

These insights have implications for further implementations of Behavior Authoring PeerPlay and for cHRI designers. Even though we developed our operationalization under the premises that tangible manipulation provides a more intuitive interaction for children [12], the findings show the opposite. We gather that the way we operationalized the Behavior Authoring PeerPlay is not sufficiently attuned to children's cognitive and motor skills. cHRI designers who would like to author behaviors involving children should explore multiple tangible proxy forms to guarantee better usability and ergonomics. Future work could present the tangible proxy as the little brother of the actual robot platform to support children's understanding of the kinesthetic imitation mechanisms. Another option is to create a playful scenario in which the big brother mirrors the little brother. Alternatively, designers could devise a collaborative Behavior Authoring PeerPlay between robot designers and children to scaffold children's understanding of the activity. Another option is to use the Wizard-of-Oz metaphor to facilitate children's in authoring a robot's behavior. Children could take the robot of the Wizard-of-Oz and manipulate a tangible proxy hidden from other children. In this way, children who observe the robot behavior might experience less confusion. Another way is to focus only on the proxy and record the proxy's motion to translate them into the actual robot platform.

All in all, the findings from the Behavior Authoring Workshop indicated that while promising, the Behavior Authoring PeerPlay activity is not yet sufficiently attuned to children's cognitive abilities and motor skills. We suggest that the activity should be simplified and scaled to the variety of fine-motor skills of children. However, our attempts to author behaviors had a low degree of success even if delivered with a very child-friendly and potentially appropriate activity. We still believe that authoring robot behaviors with children could eventually lead to behaviors that consider children's perspective. Indeed, the activity supports children's expression of their understanding of agency. Behavior Authoring PeerPlay facilitates children in elaborating narratives and explanations about the interaction. Still, we think that more research is needed to find the best format to co-author robot behaviors with children.

5.3.5 *Behavior Authoring PeerPlay Workshop: Conclusions*

We developed Behavior Authoring PeerPlay as an activity geared to the last stages of designing a robot's behavior. Behavior Authoring revolves around cycles of "diving-in", "stepping-out", and reflection. It stems from

pretend play and perspective-taking, but it focuses more on pretend play's imitative aspects. Behavior Authoring is thus a sophisticated form of puppeteering, in which children use a tangible proxy to control and author behaviors in a robotic platform. We understand that a tangible proxy provides a more coherent mapping to externalize and embody children's enactment of a robot's behavior through a pilot study. Hence, we decided to continue exploring a kinaesthetic interaction paradigm for behavior authoring.

In a co-design workshop, we examined whether the tangible proxy enables children to author given behaviors and whether kinaesthetic imitation between a proxy and a robot platform enables children to reflect on the sequence of the intention behind the interaction.

Surprisingly, our findings show that while promising the operationalization of Behavior Authoring PeerPlay is not effective nor efficient to author given robot behaviors, but it does enable children's reflection. We provide several interpretations of our findings, along with suggestions for improvement. Our insights suggest that the cHRI process to author behavior should be further democratized to enable children's involvement. We leave these possibilities for future work.

5.4 CHAPTER CONCLUSION

Designing for children while being adults is challenging. The ways children interpret and perceive robots' non-verbal behavior might surprise (and have surprised) designers and researchers. In the dissertation, we actively investigated how to bridge the knowledge gap between designers and children. We focused on co-design, a human-centered design approach supporting people's involvement in the design process to co-create and co-making sense. We asked ourselves how we could co-design with children and which method could be suitable to co-design the non-verbal behavior with children. Crucially, we sought to understand how to facilitate the emergence of the tacit knowledge children have about their experience and perception of robots, a complicated question to pose, given the scarcity of HRI literature on co-design.

To answer our question, *RQ5. What method is suitable to co-design the non-verbal behavior of a robot with children?* we perused the literature of children's development of agency and the CCI and cHRI literature. Through analysis of the CCI and design-research fields, we identified co-design as an approach providing a framework for methods that facilitate children's co-creating and reflecting about a robot's behavior and agency. We worked on translating the theory into co-design activities by reviewing existing methods and techniques. We gathered that focusing on pretend play activities would support children's creativity and reflection, particularly role-play and perspective-taking exercises. Moreover, we conclude that embodied activities could support children's cognitive unloading and enable them to express their views about a robot's agency. Therefore, we deem embodied role play

and perspective taking activities as suitable to co-design the non-verbal behaviors with children. We called the resulting method Perspective Taking in Embodied Role-Play (PeerPlay). The method consists of two activities: (i) Exploratory PeerPlay is an activity for the initial design process, which entails body-storming and puppeteering (ii) Behavior-Authoring PeerPlay is an activity for the prototyping phase in which children author a robothing's behavior by puppeteering a tangible mini-robothing controller.

Insights

We applied the PeerPlay in two workshops. The insights from the Exploratory PeerPlay show that children could express their tacit knowledge about how a robot should move to communicate goals, intentions, and social attributes in collaborative play with children. By enacting the robothing's behavior, children elaborated on the motion elements that, according to them, expressed intentions and social attributes of a robot. Children were readily able to discuss what they perceived the movements to communicate in context. They were able to provide explanations, often blurring a casual explanation with a psychological explanation. These explanations are a window into how children conceptualize a robot's agency in an interaction context. Typically, children find it hard to communicate about it, and we observed that PeerPlay facilitates them to communicate about it. Interestingly, we noticed that children build a sort of '*character*' for the robot from the interplay of the actions and the motion-style. We have gathered early insights into how children associate certain motion elements with particular intentions or social attributes. All in all, Exploratory PeerPlay yields low-fidelity prototypes of robot behaviors and facilitates children to engage in-depth reflections about a robot's agency in an interaction scenario. cHRI research could apply Exploratory PeerPlay to kick-off the design process with children. The low-fidelity prototype could provide cHRI researchers with many motion elements to use as building blocks of a robot's behaviors. The reflections could support the decision making in the design process, motivating design choices with children reflections. The Exploratory Peer Play activity is low-fidelity, low-cost, and portable; thus, it could be easily implemented to explore robot behavior design.

Exploratory Peer-Play has some limitations, mainly due to its operationalization. Still, we argue that he provided us with rich insights about how children make sense of robot behaviors, which would have been hard to gather only with user testing activities. We anticipate that Exploratory PeerPlay needs to be tested in more scenarios, contexts, and cultures. It should be evaluated with roboticists to assess its generative potential and what is possible to do with the co-design outcomes. Moreover, the Exploratory PeerPlay's findings provided this dissertation with rich insights on how children design and interpret a robothing's behavior to communicate prosocial, antisocial, and passive intentions in collaborative play. After the workshop, we asked ourselves how to translate the co-design outcomes into a robothing. We explore this in Chapter 6.

The Behavior Authoring Workshop findings indicated that while promising, the Behavior Authoring PeerPlay activity is not yet sufficiently attuned to children's cognitive abilities and motor skills. Children found it hard to author the robot behavior because they experienced poor usability and poor user experience with Brobotino, a tangible mini-robot controller proxy. Apart from technical challenges, we think that it is too complicated for children to puppeteer the actions of a real robothing with a mini-robothing controller. We suggest that the activity should be simplified and scaled to the variety of fine-motor skills of children. Moreover, the usability issues hamper children's reflections about each other design making it difficult for designers to understand children's sense-making and behavior explanation. Despite the challenges that children experienced while engaging in Behavior Authoring, we noticed that the activity, even with its flaws, stimulated children to express their points of view about the robot's behavior and the narrative behind the interactions. We anticipate that with a better-designed proxy and enhanced activity, Behavior Authoring could be an asset for cHRI research to co-design behaviors with children.

Overall, we conclude that Exploratory PeerPlay is suitable for co-designing non-verbal robot behaviors with children, while Behavior Authoring should be further developed.

*Reflections,
Opportunities, and
Limitations*

Reflecting on the PeerPlay method as a whole, the method involved children as informants specifically for the design process's early stage. However, we anticipate that – similar to what happened in CCI – children's role could be broadened to a full design partnership, in which children are involved during the whole design process. Our insights suggest that we would need to democratize the child-robot interaction design practices to make it more accessible to children for a full design partnership. Otherwise, children would experience the same challenges we have observed in the Behavior Authoring PeerPlay activity; thus, it would be too difficult for children to collaborate with the researchers. Our attempts to author behaviors had mixed successes even if delivered with a very child-friendly and potentially appropriate activity. On the other hand, Exploratory PeerPlay is a promising activity that researchers can use to kick-start the cHRI design process. Moreover, we think that Exploratory PeerPlay could be used to explore how children understand a robot's mind and explore which behavior children trust by enabling in-depth reflection about robothing intentions and intelligence.

PeerPlay lays the groundwork for designing a robot's agency responsibly, mindful of the ethical and social implication of deception and mismatch of children's expectations. Co-designing a robot's agency by engaging children in co-pretense exercise could help cHRI designers embed a fruitful suspension of disbelief in cHRI. Further developments of PeerPlay should support children in grasping what it means for a robot to interact with them autonomously, the boundaries in the suspension of disbelief, and how to explain the social intention of a robot critically.

Lesson Learnt

Simultaneously, the PeerPlay method could be considered laborious by cHRI researchers because it increases the number of activities to carry out with children, a notoriously difficult target group to be involved in research activities. Moreover, cHRI researchers might find PeerPlay inefficient because it produces many qualitative data that needs to be systematized, parsed, and distilled into insights for cHRI design. However, we believe that the quality of the insights that the Exploratory PeerPlay activity and, to a lesser extent, the Behavior-Authoring PeerPlay deliver justifies the effort because it enables a window into the way children make sense of robots. We do only apply PeerPlay to the design of non-verbal behaviors for low/non-anthropomorphic robots. Still, we anticipate that it could be applicable also for the verbal behaviors of human-like robots.

All in all, we cannot claim this is a validated method yet. More systematic evaluations of the method are needed with a more significant and diverse cohort of children. Nevertheless, we conclude that a co-design method that entails activities focused on perspective taking and embodied role-play enables children to co-design a low/non-anthropomorphic robot's non-verbal behavior.

Part II

DESIGN AND EVALUATION OF A ROBOTHING TO PROMOTE CHILDREN'S COLLABORATION THROUGH PLAY

PUSH-ONE: NON-ANTHROPOMORPHIC AND NON-VERBAL ROBOT TO PROMOTE CHILDREN'S COLLABORATION THROUGH PLAY

“Blocks seem so basic. And yet, we find them teaching the architect and the scientist, the fabulist and the fact finder.”

Jessica Lange (2018) ^a

^a I suggest to listen to **Golden Phone** and **Turn me well** by Micachu & The Shapes while reading this chapter.

Chapter 6 presents the design process of Push-one, a proof-of-concept robothing. Taking a movement centered approach, we translate the movements children have designed during the Exploratory PeerPlay workshop into a remotely controlled robothing prototype. Push-one's embodiment follows its function (what it does) and its communication (what it wants to achieve by interacting). The result is an abstract, non-anthropomorphic, non-verbal, animated wooden-toy that assembles geometrical wooden puzzles. Push-one is remotely controlled and mobile; it has holonomic locomotion. It can move in any direction; it has non-reprehensible manipulation. It can push-objects in a specific direction to a shovel-like front. Push-one operates specifically during children's conflicts around the possession of objects. If children start conflicting about the possession of an object, Push-one gives an extra one to them. Or, it takes away the object children are fighting over to forcibly stopping the fight. These actions represent a way to intervene in the conflict, and they underline strategies children naturally use to resolve disputes. By doing so, Push-one operates to stimulate children to reflect on the conflict and find a way to be prosocial. As a result, Push-one does not tell kids how to behave in conflict, what actions to take. Push-one is designed to enable children's independent reflection-in-action about their prosocial or antisocial behavior in a game rather than dictating how it is right to act. Push-one's behavior is empirically tested in Chapter 7 and Chapter 8.

The chapter is partially based on: **Zaga, C., Jung M. F., Truong, K.P. and Evers, V.** *My New Toy is a Robothing: Designing Non-anthropomorphic and Non-verbal Robots to Promote Children's Collaboration Through Play.* ACM Transactions on Human-Robot Interaction (in preparation).

Push-one was selected for and exhibited at the **International Dutch Design Week (DDW)**, part of the Design United exhibition "Up Close and Personal"¹.

The design and fabrication of Push-one was carried out at The Robots in Groups Lab of the Cornell University in collaboration with dr. Malte Jung, Hamish Tennent, and other members of the laboratory.

¹ <https://2020.design-united.nl/day-1-hybrids/responsible-design-of-human-agent-interaction/>

6.1 CHAPTER INTRODUCTION

The embodiment of a robot impacts how humans perceive and interact with a robot. There is a delicate interplay between a robot's form and a robot's behavior. The social affordances of a robot depend on the embodiment's static properties and dynamic properties of its behaviors. Therefore, the design of a robot's embodiment should go hand in hand with designing a robot's behavior.

The Exploratory PeerPlay's findings (see Chapter 5) provided us with rich insights on how children design and interpret a robot's behavior to communicate prosocial, antisocial, and passive intentions in collaborative play. After the workshop, we asked ourselves how to translate the co-design outcomes into a robot. We pondered whether an existing platform could embody children's designs well. We gathered that the co-design outcomes could be the starting point to design a robot that communicates to children how children would like it to communicate. We considered the motion elements designed by children and the reflections we gathered on children's designs as a potential starting point to shape a proof-of-concept robot. The challenge was to translate the motion elements and insights about the children's interpretation of these movements into a functioning robot. To this end, we took a **movement centered approach**. A movement-centered approach described by Hoffman and Ju [151] iteratively examines how kinetic behavior relates to surface embodiment. This approach's focus is on designing motion so vividly expressive that it is not necessary to resource to human-like cues and embodiment. Thus, the movement-centered approach shares our (i) focus on surfacing people's tacit understanding of non-verbal communication to use it to design for a with people (see Chapter 5), and (ii) interest in exploring low to a non-anthropomorphic embodiment.

Embodying children's designs and our framework

Embodying children's design

In this chapter, we detail the design process to design a robot from children's movement designs. We provide in-depth details about the design process, elaborating each design decision thoroughly. We explain how we distilled robot's behaviors from the co-design workshop outcomes and how we embodied them in a robot platform. We describe interaction scenarios that contextualize the cHRI. Last, we describe insights from the informal play-tests with adults and children, which we carried to evaluate the embodiment and interaction design informally. We conclude with a reflection on our design process and methodological implications. Although a robot prototype is the main output of the chapter, the design of the robot behavior and interaction is, in fact, at the core of the development of the robot prototype. Therefore, the chapter inform the second research question of the dissertation, RQ2. *How should the interaction with a robot be designed to impact prosocial dynamics in play?*) and the third research question of the dissertation RQ3. *How should the non-verbal behavior of low/non-anthropomorphic robots be designed to communicate a robot's intention to children?*).

About this chapter

6.2 DESIGN VISION, PRINCIPLES, APPROACH AND PROCESS

In this section, we give an overview of our design vision, our approach’s rationale and why we considered a movement-centered approach suitable. Then, we review our principles and guidelines to include form and motion style as variables to design robotothings. Lastly, we provide details about the design process.

6.2.1 *Design Vision*

When designing an artifact of any kind, designers develop a design vision. A design vision articulates the general direction a design and the values a design embodies [234, 143].

We formulate our design vision as follows: We want to design hybrids between social robots and toys, i.e., robotothings. The function of robotothings is to promote collaboration through play. In practice, we imagine robotothings playing with children in object-oriented games. Robotothings intervene in the reciprocal and prosocial dynamics naturally occurring in playful interactions among peers with helpful actions. We want to design robotothings for children in their middle childhood (7 to 11 years old), a developmental stage where children refine their collaborative skills (See Chapter 2). Context-wise, we imagine the interaction between a robotothing and children taking place in playful contexts, either in educational or familiar settings.

We conceptualize the role of a robotothing as an interactive “*thing*”, rather than a human-like partner (e.g., teacher, friend etc...). We consider robotothings as technologies bringing a specific set of **values** to the interaction with children: (i) **Children’s independent reflection in action**: by intervening in play *by playing* with prosocial actions in the game, the robotothing enable children’s thinking about prosocial behaviors. A robotothing should not indicate the children what actions are right to take but should stimulate reciprocity or other prosocial dynamics to enable children’s reflection-in-action in collaborative play. (ii) **Children’s agency over the robot’s agency**: in the interaction with robotothings, children are the primary agents, ultimately in charge of the interaction. While a robotothing aims to influence children’s behavior, the robotothings does not have a normative function. It is a vehicle of playful reflection; it does not have control over children’s behavior.

We consider the design vision during the design process. We re-evaluate our design vision at the end of the design process to reflect upon the design outcomes.

6.2.2 *Design Approach*

In line with our conceptual framework, we chose a design approach stemming from HRI, but grounding in the design-research tradition, that

place the design of a robot's behavior at its core. Initiated by Hoffman and Ju [151] and brought forward by an increasing number of scholars [333, 344, 355, 356, 359], the movement centred approach focuses exploring robot kinesis (i.e., motion) as a potent interaction and communication medium with humans (for an overview of HRI design methods see Chapter 2).

The movement centred approach is geared to surface the people's tacit knowledge about non-verbal behaviors and use this knowledge to carefully design robots. The form of the robot is somewhat subordinated to the motion design, leading to *"mechanically and formally simple robots that display sophistication in the way they move instead of in the way they look"* p. 95 [151], like everyday-objects robots (e.g., doors, ottomans, microphones) [181, 333, 359], or abstract robots [150, 154]. Designing with movement in mind (as defined by Hoffman and Ju [151]) is a process that factors in mechanics, expressiveness, aesthetics, and user experience through iterative design explorations.

Typically, motion and movements are explored at various degrees of approximation, simulating them with sketches, 3D animation studies, or theatre-like exercise. Lay people or experts of movement such as actors or dancers often participate in the exploration of motion and movements; VHRI and WoZ studies are common to nail the behavior design *before* designing a full-fledged robot. No matter the method, the robot's form follows the behavior and the motion.

Following the movement centered approach and our framework, we start by exploring how the robothing moves and evaluate how the robothing's movement related with a physical appearance. The movement centered design approach appears to distinguish between functional (which Hoffman and Ju [151] call pragmatic) and expressive motion of robots, focusing predominantly on the latter. While functional motion is the motion to deliver *"actions performed to bring one physically closer to a goal"* [151] (p. 92), expressive motion communicates a robot's state and emotion. Conversely, in our conceptual framework, we posit that functional and expressive motion go hand in hand: goal-directed behaviors can communicate a robot's internal state. Therefore, in the design approach we take, **"we do not distinguish between functional and expressive motion"**.

In the next section, we discuss our design process based on the movement-centred approach.

6.2.3 Design Process

Our design process is semi-participatory. Children are involved early in the design process informants (See Chapter 5) [88], and researchers use the knowledge generated by and with children to continue the design process. Method-wise, our process uses a battery of design methods from HRI and design-research.

Figure 44: We re-proposed the conceptual framework introduced in Chapter 2 as a reference for the reader.

Our process (See Figure 46) starts from the outcomes of children's co-design sessions, specifically from Exploratory Peer-Play (See Chapter 5). The ultimate goal is to make the knowledge we gathered explicit and actionable. Therefore, we explore the motion elements using the Exploratory PeerPlay method developed in Chapter 5. The design explorations represent an intermediate step to distill robot behaviors from co-design activities' outcome. The explorations and visual representation helped us formalizing the behaviors of the robothing.

Then, we translate **the behaviors into form**, exploring how the behaviors related to surface appearance. We reflect upon the design metaphors and the shape of a robothing's movement. In this phase of the process, we develop low and middle fidelity prototypes of the robotic platform and the embodiment of the robot.

Our third step is to define the **interaction and scenarios**. We implement the scenarios we have already explored with the children further. We work to carefully imbue the scenarios with the insights from the reflection with children. Lastly, we **play-test the robothing, the interaction, and scenarios**. The qualitative insights inform the final design of the robothing.

6.2.4 Revised Design Principles and Guidelines

In Chapter 2, we have introduced our conceptual framework. From the framework, we have proposed seven actionable design principles to guide the design of robothings behaviors (See Figure 45). Here, we revise and integrate the design principles to account for the insights for the co-design workshop and to integrate principles to guide our design of a robothing's embodiment.

In Chapter 5, we have seen that children make use of a robothing's movements to communicate a robothing's intention, but make occasional use of motion-styles to reinforce or nuance the actions of the robothing. We gather that children appear to infer a "*character*" for a robothing from the interplay of movements and motion parameters. We take these insights cautiously, as we cannot draw definitive conclusions from the co-design workshop outcomes. However, we consider motion parameters and **revise** our **fifth design principle** as follows: (v) **Action=social communication**. The actions of a low/non-anthropomorphic robot should embody communication's goal. Motion parameters that stylize the movements can be applied to reinforce or nuance the robothing's intention.

Form Design Principles

We elaborate **two additional design principles** which we take into account to design **the form** of a robothing, that is the surface appearance and embodiment of a robothing. The form of a robothing to not cause a mismatch between its function (what it does) its communication (what it wants to achieve by interacting), and what a child may infer from the robot's appearance. There should be a balance between a realistic non-anthropomorphic form (i.e., a form that is familiar because similar to already existing objects, for instance, a toy) that can ease children's understanding of the function of a robothing with an embodiment that is coherent with the behavior of a robothing. Thus our additional principles are:

- (viii) **Form/behavior/function adherence**: The form and the non-verbal behavior of a robothing should follow the imagined function of a robothing. We should maintain the correct expectations about the robothing's capabilities. Therefore the embodiment should not create false expectations of what the robothing can do or be endowed with physical social cues beyond its function. Our perspective is to establish a developmentally and ethically appropriate *illusion of life* that could be beneficial to influence children's prosocial behaviors.
- (ix) **Familiarity**: A robothing form should have a connect connection with realistic non-anthropomorphic form, even if abstract. The embodiment of a robothing should balance realism and familiarity with the technical and aesthetic requirements. We strive to design interaction between the robothing and the children that, in the long run, might establish a thing/toy-like relationship between children and robothing.

We follow these design principles throughout the design process, and we reassess them at the end of the design process.

6.3 FROM MOVEMENTS TO BEHAVIORS

The first step in our design process is to define a robothing's behaviors from the movement co-designed with children (See Chapter 5). In this section, (i) we discuss the central insights of the co-design workshop with

Figure 45: The figure shows the seven design principles introduced in Chapter 2 and the 2 additional principles regarding the form and embodiment of a robothing.

children. Second, (ii) we select goal-directed motion, motion parameters, and trajectories children use to enact a robot behavior. Third (iii), we carry out an embodied design exploration to re-enacting the selected motion elements and understand whether those movements would still replicate. From this embodied exploratory activity, we learn that finding a visual representation of the motion elements would help distill the behaviors. Fourth (iv), we explored ways to represent the motion elements to communicate them visually and further define the movements easily. Fifth (v) from the movements, we define three actions, one per robothing intention, and three motion-style which nuance the actions. Actions and motion-styles are the building blocks of robothing behaviors that underline prosocial, antisocial and passive intention in collaborative play.

6.3.1 Outcomes of the Co-design Workshops with Children

During Exploratory PeerPlay, we have co-design with children various robothing's intentions to intervene in collaborative play. Children puppeteered the movements of a low-fidelity robothing puppet in a given scenario. Children enacted the actions and intent of the robothing puppet and reflected on each other "designs". Through analysis of the co-design outcomes, we have found that children enact a robothing intention using several actions, i.e., goal-oriented motion, and some motion parameters, i.e., the way motion is delivered. From the outcomes, we infer that:

- **Children use a robothing's locomotion as the main means of communication:** When puppeteering a robothing behavior, children predominantly use the robothing locomotion to enact the goal-directed

Figure 46: The figure visualizes the design process to develop Push-one, a proof-of-concept robothing. As such, the figure refers to the design process of Chapter 6 and its connection with the methods/research of the preceding and following chapters. For an overview of the dissertation’s approach and methods, please refer to Chapter 1.

behaviors. When reflecting on their designs, children describe the locomotion as giving/distributing objects towards or away from children or just sorting. Children imbued the robothing puppet given to them with prosocial, antisocial, and passive intentions, thereby “designing” the behaviors of the robothing. In their enactment, they move the robothing puppet back and forth using the puppet’s base as if it was a shovel to push objects around the space and towards children in the fictional scenario. Children make use of other movements like jumping and wiggling and rotation of the base, but they appear not to be as common as locomotion is.

- Children layer motion parameters onto the locomotion to reinforce or nuance a robothing intention:** We show that children use Laban efforts such as motion parameters of space and weight to stylize the motion. A parameter of space in the Laban System indicates whether the motion has a direct trajectory or an indirect trajectory. Children used direct and indirect space trajectory profusely. In particular, we noticed that when children design a prosocial intention of the robothing, they often use indirect trajectories meandering in the space. When children design a antisocial intention, they make more direct trajectories, shaping the motion in straight or broken lines. Children also use a combination of direct and indirect space trajectories, but with low frequency. A parameter of weight defines how a robothing uses its body weight when moving. A strong weight indicates that motion is delivered with force and power, while a light weight indicates that motion is delivered delicately. Children mainly use a light weight, but they often use a strong weight when enacting a antisocial behavior.

Again, children use other motion parameters, such as time (a parameter of speed in the Laban system), but not as frequently as weight and space.

- **Children use locomotion to make clear the recipient and objects of a robothing behavior:** The behaviors children design aim at the recipient and the object of the communication act: children direct the actions of a robothing to the people the robothing is communicating with (recipients) and towards the objects of the communication. When children enact the locomotion, they make clear trajectories: locomotion is directed towards or away from recipients or objects. When children design for a prosocial intention, they appear to direct the locomotion mainly towards recipients and objects, while for a antisocial intention mainly away from recipients.

Table 19 summarizes the motion elements used by the children to enact a robothing's intention, thereby "designing" the robothing behavior. The motion elements are the starting point of our design process. Additionally, from children's reflections of each other robothing's behavior design, we learned that children imbue the robothing with prosocial, antisocial and passive intentions, but also render a sort of '*character*' for each of the robothing behaviors. Along with describing the intention of the robothing, children attributed affective states and social qualities to various movements. However, the variability of attributions is too high to identify well-defined characters. We attribute this characterization to the motion parameters, and we will keep this into account while distilling behaviors.

Overall, the robothing's behaviors designed by children consist of goal-directed motion and trajectory, and motion parameters layered one with the other. Each robothing's intention appears to have a specific combination of motion elements to communicate and reinforce the underlying intention. For each intention, in the next section, we distill a set of movements to define a set of robothing's behaviors.

6.3.2 *Selecting Motion Elements*

As we have seen, children enacted the robothing's intention with a variety of movements. To distill robothings behaviors for our design process, we **select** a combination of goal-directed motion, motion parameters, and direction of motion from the movements generated by the children. The primary rationale of the selection is frequency. Therefore, we selected the goal-directed motion, motion parameters, and direction of motion that were more frequent for each robothing intention.

The resulting selection is as follows (see items highlighted in bold in Table 19): For the behavior underlining a **prosocial intention** of a robothing, we selected **locomotion to push objects** as goal-directed motion, lightweight, indirect space and sustained time as motion parameters, and going towards

Co-designed Robothing Behaviors			
Behaviors:	Prosocial Intention	antisocial Intention	Passive Intention
Actions: goal-directed motion	Locomotion: Pushing objects Rotation: moving on x and y axis Elevation: jumping, wiggling	Locomotion: pushing objects, scattering objects, stepping onto objects Rotation: moving on x- and y-axis Elevation: jumping, wiggling	Locomotion: pushing objects, sorting objects Rotation: moving on x- and y-axis Elevation: -
Laban Efforts: motion parameters	Weight: light Space: indirect Time: sustained	Weight: heavy Space: direct Time: sudden	Weight: light Space: indirect and direct Time: sustained
Trajectory: direction of motion	Towards recipients Towards objects	Away from recipients Towards recipients Towards objects	Away from recipients Towards recipients Towards objects Away from objects

Table 19: The table summarizes the actions (goal-directed motion), the Laban Efforts (motion parameters), and trajectories, (direction of motion) children have used to design prosocial, antisocial, passive intentions of a robothing. In bold, the actions, Laban Efforts, and trajectories that were observed with more frequency in the corpus of co-designed behaviors. For a breakdown of the frequencies and more information about the co-design study, please consult Chapter 5

objects and recipients as motion direction. For the behavior underlining a **antisocial intention** of a robothing, we selected locomotion to push objects as goal-directed motion, heavy weight, direct space, and sudden time as motion parameters, and a trajectory away from recipients. Last, for the **passive intention**, we have selected locomotion to push objects and sort objects as goal-directed motion, a light weight, indirect space, and sustained time as motion parameters and a trajectory focused on objects both away and towards recipients.

The selected combinations guide the design of the behaviors and, ultimately, the form of the robothings.

6.3.3 Exploring the Selected Motion Elements

We have selected motion elements used with more frequency by the children to enact each robothing intention. Therefore, we are not replicating one-on-one all the behaviors children designed in the co-design sessions. However, we are distilling the most relevant motion features to combine into behaviors.

As such, we face the challenge of replicating the motion elements children “*designed*” with high granularity and enough fidelity to capture what children wanted to communicate. We (the designers) need to have a shared understanding of the selected motion elements and explore how to “*materialize*” them into form. Moreover, the motion elements we have selected should carry their intended meaning well: the motion should be aligned as much as possible with the meanings applied to the children. Within the “*movement centered*” design approach is customary to carry out design explorations to facilitate design’s team activities, by surfacing tacit knowledge about interactions (See the work on Embodied Design Improvisations by Sirkin [332]) or exploring the design space of a robot’s movement [344].

Drawing from these experiences, we carried out design explorations with the research team. Our goal was threefold: (i) we wanted to size-up the movements generated by the children, (ii) we wanted to understand how to make the knowledge gathered through the co-design sessions explicit and actionable (ii) we wanted to reflect on the movements' replicability to inform our subsequent explorations of the robothing form. To this end, we make use of our Exploratory PeerPlay method doing exercises of enactment and reflections (See 5).

The research team did a series of puppeteering activities. Researchers used various objects bearing different non-anthropomorphic morphology and degrees of freedom (i.e., a pen, a cube, a meter, a wheel). The researchers consulted the table describing the goal-directed motion, the motion parameters, and trajectory to enact the behaviors. After the enactment, researchers asked each other questions about the movements. Researchers described their enactments with each other and reflected on how well the enactments replicated what children did. The activity ended with a general discussion, where researchers watched the videos from the co-design activities with children as a reference point.

The main insights from the exploratory activity were: (i) Motion parameters are often difficult to replicate with high fidelity, particularly parameters for antisocial intention. To some extent, the difficulty in replicating the motion parameters lies in their formalization (i.e., Laban Efforts). Some researchers enacted the antisocial intention describing the motion parameters as 'jerky' locomotion, while others more with 'zig-zag' locomotion. 'Jerky' and 'zig-zag' emerged as terms to describe the antisocial motion parameters while researchers reflected on each other enactments. The motion parameters definitions of the Laban effort System were often deemed as too opaque for the researchers to find common ground. Therefore, the researchers suggested finding more transparent terms to define the motion parameters to dissipate confusion and facilitate actionability. (ii) Similarly, the researchers felt that a visual representation of the motion elements rather than verbal would help tease the behaviors apart, way more than a written description. (iii) Researchers gathered that goal-directed motion and trajectory overlap with each other into deliberate actions, while motion parameters provide nuance and stylize the movements providing extra meaning. An observation in line with what emerged from children's co-design activities (See Chapter 5). Researchers suggested that defining clear *motion-styles* would help the design effort. (v) In general, researchers described the motion and its underlying intention as children did. While the intention behind goal-directed actions and trajectories are reasonably easy to discern, motion parameters can sometimes be opaque. Children used motion parameters to nuance the intention with social qualities (e.g., being helpful or nasty), but researchers often did not attribute any social qualities to the various combination of motion parameters and goal-directed motion. A possible explanation is the cognitive/knowledge gap between children and researchers. Nevertheless,

researchers suggested iterating on the motion parameters further in the design process.

Overall, the design explorations represent an intermediate step to distill robot behaviors from co-design activities' outcome. Through the design exploration, we have learned that we need to reconsider how we formalized the motion elements – motion parameters in particular– and that a visual representation is needed. We gathered relevant insights about how to combine the motion elements and about their replicability: we have identified the need of better defining and iterate on the motion parameters . The next step is to elaborate on these insights to distill the final behaviors.

6.3.4 *Visually Representing the Motion Elements*

The design exploration made clear the need of a visual representation of the motion elements. Therefore, the research team worked on defining a visual representation of the motion elements. We focused on generating abstract **two dimensional representation** of the movements to facilitate the visual communication of the motion elements and help us to further define them.

The rationale behind a two-dimensional representation for the motion elements was two-fold: (i) We sought to detach the movements from any specific tridimensional form to distill them into their core aspects. We know from literature [142, 250] that abstract representations of movement can be interpret by human as intentional. Therefore, we thought an abstract two dimensional representation could help us encapsulating intentions and motion elements in a clear way. (ii) We sought to make visualize and materialize the motion elements to facilitate further explorations about the form these motion elements should eventually take.

To this end, we carried out a sketching sessions. We focused on outlining a visual representation of each selected motion element as outlined in Table 19. We **sketched** the motion elements first in isolation and then we combined them by layering them. Each member of the team generated a series of sketches. The team visualized the motion and motion parameters in various ways: dots paths, lines paths, and primary shapes. After the first sketching session, we discussed each other sketches to reflect on commonalities, patterns, and differences in the visualizations. We gathered that the prosocial motion parameters were mostly sketched with curvilinear and sinusoidal with smooth meandering lines, while the passive locomotion path with straight, monotonous lines. The antisocial motion parameter (again) subject to variability: the majority of the researchers sketched it with jerky, staccato-like lines, but some included some zig-zagging lines. No matter the shape chosen, researcher visualized the motion elements in lines with arrows for trajectories.

After resolving differences, we selected nine representations, each a combination of the various motion elements. The goal-directed motion of

pushing objects was visualized as a line dragging a triangle to people/objects, while the goal directed motion of sorting as a line going in multiple directions. Prosocial motion parameters were visualized as a sine-wave curve, antisocial motion parameters as a broken line, and passive motion parameters as a straight line. Trajectories were visualized adding an arrow at the end of the lines. The research team considered the resulting representations as clear and helpful to have a shared understanding of the motion elements.

The resulting visual representation were used to finalize the definition of the robothing's nonverbal behaviors and as a starting point to elaborate the form of the robothing.

6.3.5 *Robthing's Behaviors: Distilling Actions and Motion-Styles*

The exploration of the motion elements and their visual representation gave us insights to define the robothing behavior. In this section, we distill the '*building blocks*' of the robothing behaviors to focus on in our design process.

First, we re-define goal-directed motion and trajectory into three actions which better describe the movements designed by the children: **giving objects** to a child/children by pushing and object, **tacking objects** from a child/children by pushing and object and sorting alone. The actions are represented as locomotion towards or away from children while moving an object.

Second, following the insights of the exploration, we decided to re-defined the motion parameters (which we formalized using the Laban Effort terms) to guarantee a more descriptive formalization. As suggested by the research team, we re-defined the motion parameters as three **motion-styles**: **asine-wave motion-style**, a **jerky motion-style** and a **straight motion-style**. The motion-style indicates the *the way* the motion is delivered. We maintain the description of the Laban efforts underlying the motion-style, thus retaining the original meaning, but we apply to each parameter a name that is more descriptive of the *actual* way the motion.

The result is a total of 9 building-blocks of a robothing behavior: three actions and three motion-styles (See Table). Faithful to the children's design, we combine a sine-wave motion style with a giving action, a jerky motion-style with a taking action and a straight motion style with a sorting action. We use the two-dimensional representation we have generated to summarize the distilled actions and motion-styles. The description of the behaviors as well as the visual representation of the behavior is the starting point to give form to the behaviors.

Drawing from the insights of the co-design workshop, we should clarify that both actions and motion-style communicating the function, the intention and social qualities of the robothing. we anticipate that motion-styles and actions combination should be carefully evaluated with children, to

check whether the motion-style indeed nuances the perceived intention of a robothing. We leave this question to empirical evaluations of the robothing prototype (see Chapter 7).

6.3.6 *From Movement to Behaviors: Conclusions*

In this section, we have described the first step in our design process: from movements to behaviors. The result of this step of the design process are three actions and three motion styles related to prosocial, antisocial and passive intentions. Actions and motion-styles are the building blocks of the robothing behaviors that guided the design of the form and interaction of the robothing.

6.4 FROM BEHAVIORS TO FORM

The second step in our design process is to translate the building blocks of the robothing behavior into form, i.e., the way the robothing looks. In this step, we co-developed the physical form and the behavior of the robothing, which we have defined in the previous section. At this stage, the process is lead by researchers. Method-wise, we used remote control activities from our PeerPlay method, together with sketching and physical/digital prototyping. We used these methods to implement and explore hardware and software that afford the actions and motion-styles selected.

In this section, we describe the considerable iterations we have taken to explore how the actions and motion-style we selected relate to possible forms. As a result, we elaborate upon the design principles of form/behavior/function adherence and familiarity. Then, we illustrate the design exploration undertaken to understand better what type of locomotion best replicates the actions and motion-styles. We detail the technical requirements of the behaviors. Third, we describe the hardware and software we used to design the first prototype of the robothing platform. Fourth, we elaborate on the design metaphor to guide the design of the robothing surface appearance. Lastly, we detail how we translated sketches of the robothing form into 3D printed prototypes and introduce the final prototype of the robothing.

6.4.1 *Giving Shape to Actions and Motion Styles: Selecting The Type of Drive*

The actions and motion-styles we have distilled have particular characteristics that not only inform but also constraint design decisions around the robotic technology to develop. At this stage we need to make the behavior tangible and develop prototypes that can afford both actions and motion-styles. The actions and motion-styles we have distilled from the co-designed behavior all represent ways in which a robot traverse a space

pushing objects towards specific directions. Hence, to give shape to actions and motion styles, we need to explore how well the kinematics of mobile robot platform affords them.

By robot platform, we mean the hardware, the software, and the surface form of a robot. Therefore, to explore the hardware kinematics and dynamics, we needed to replicate action and motion-styles. In particular, we focused on understanding how the mobile robot should physically move in the space to replicate the behaviors. We explored various kinematics, but without building a prototype yet. Our goal was to simulate how the movements could take shape and get insights about how to materialize the movements without embarking yet in a development effort. Thus, we started by exploring the design space of locomotion of the robothing by simulating the actions and motion-styles in already existing mobile robots platform. We simulated the behaviors by remotely controlling existing robotic platforms (similar to our workshop number 2 in Chapter 5). Given our design vision, namely to design a non-anthropomorphic robothing that is safe and robust enough to move objects in the space and interact with children, we decided to explore the design of a robot platform that uses wheels for its locomotion. The robotic platforms we chose only consists of chassis and wheels. Then, we specified the type of drive of the mobile robot.

The research team tested explored three different type of drive, car drive, differential drive (i.e., two separately driven wheels placed on either side of a robot body) and holonomic drive (i.e., the wheels can move in all directions) simulating the three actions and motion-styles. The procedure was as follows: one researcher simulated the behaviors using a remote control joystick, while another would observe them. Both researchers would then reflect on which drive better render the actions and motion styles, which drive has the most advantages and disadvantages in terms of maneuvering.

All in all, the tests and reflections suggest that the differential and holonomic drive are the most promising to render actions and motion-styles. Therefore, we continued our exploration with these two platforms.

The second step was to test how differential and holonomic drive afford object manipulation. Object manipulation means the handling and transportation of objects. We focus specifically on non-prehensible manipulation by pushing an object with the robot platform's base [246]. The robot platform not only has to afford locomotion but also needs to push objects while driving to replicate the behaviors designed by children. We needed to understand whether different drives might have an impact on object manipulation by pushing. We were aware that other variables play a role besides the robot drive, namely friction of the object both on the robot base and on the surface where the robot moves and mass distribution of the object itself. However, these variables are highly dependent on types of objects and environments; thus, we leave these considerations out at this stage.

The research team tested how each type of drives performs object manipulation by pushing by simulating the three actions and motion-styles but this time pushing many objects (a Lego block, a plush animal, and a wooden toy). The procedure was as follows: one researcher simulated the behaviors using a remote control joystick, while another would observe them. Both researchers would then reflect on which drive better render the actions and motion styles, which drive has the most advantages and disadvantages in terms of manipulation of objects. We tested the drives on a smooth surface, a linoleum floor. From our exploration, we deemed the holonomic drive to be the best fit for our design needs. Additionally, we observe that when designing the form of the robothing, we should pay attention to the design of the robotic base to aid the object manipulation.

After tests and reflections, we concluded that holonomic drive is the best drive for our design goals: it offers the kinematics and dynamics we needed. Thus, we focused on holonomic drive to build a prototype of the robothing platform.

6.4.2 *Distilling Technology Requirements*

Before designing a mobile holonomic robothing platform, we distill technological requirements to guide our prototyping activities. The technological requirements are derived from considerations about hardware, software, as well as our design principles.

As stated in the previous section, the robothing should be a mobile robot with a holonomic drive; thus, we distill the following requirements:

- **Technical Requirement (TR₁):** The robothing should have a mobile platform, not a static one. The hardware and software afford movements in the space, on surfaces such as floors or desks;
- **Technical Requirement (TR₂):** The hardware and software should afford effortlessly holonomic locomotion to replicate the actions and motion styles we have selected from the corpus of co-designed behaviors. Hence, the robothing platform should afford omnidirectional trajectories, locomotion paths, orientations, and rotations. Orientations and rotations should not only replicate actions and motion-styles but are delivered in such a way to adhere to the three design principles of grounding (i.e., grounding communication, grounding subject, and grounding objects).

Second, the main actions of the robothing are to give, take-away, or sort objects. Therefore, it does not only move in the space, but it does also manipulate objects. Children indicated “pushing” or “dragging” as a way to manipulate objects towards a destination.

- **Technical Requirement (TR₃):** The robothing should be able to manipulate objects while moving. We should focus on objects used during

collaborative play such as toys, puzzle pieces, and small everyday objects. We should focus on objects that do not self-propelled if pushed to minimize the need for extra motion. Hence the robot should be able to aim at an object on the floor and push it in various directions with a good degree of control;

- **Technical Requirement (TR4):** The holonomic locomotion should afford to re-calibrate trajectory, orientation, and speed to push an object as accurately as possible. However, the extra to re-calibrate should be minimal; thus, it should not interfere with actions and motion-styles to adhere to the design principle of legibility, action=social communication, and form/behavior/function adherence.

Hardware and software should guarantee children's safety, both physical and psychological. The mobile robothing platform is a research platform used under the strict control of researchers. Nevertheless, it is important to specify safety requirements:

- **Technical Requirement (TR5):** The mobile robothing speed need to be adequate to guarantee children's safety and perform the robothing's function. Motion and speed of the robothing platform should be moderate enough that if a child touches the robothing while in locomotion, no physical harm will happen. Children need to be able to stop the robothing at all times.;
- **Technical Requirement (TR6):** The object manipulation by pushing during locomotion should be safe for children. Should children touch the robothing or the objects being pushed during locomotion the robothing should stop;
- **Technical Requirement (TR7):** The mobile robothing platform should be controlled by the researchers to guarantee children's safety at all times.

From the safety requirements, it follows that the robothing needs to be remotely controlled. Paradigms of remote control such as Wizard-of-Oz involve degrees of deception. Following our design principles, we aim at lowering deception as much as possible and be transparent about what to expect from the robothing (i.e., the design principle of expectation balance). Thus:

- **Technical Requirement (TR8):** We should not implement hardware and software that imbue the remotely controlled robothing of capabilities that cannot be replicated in an autonomous version of the robothing;
- **Technical Requirement (TR9):** The functioning of the robothing should be clear to children before and after debriefing about the remote control of the robothing;

Figure 47: The figure shows the first prototype we assembled together with its parts. The prototype has low-cost accessible holonomic hardware from a customizable do-it-yourself omnidirectional wheel chassis kit by Wicked Device LLC.

We distilled nine technical requirements to guide us in the design of hardware and software of our robothing prototype. We review each technical requirement at the end of the design process.

6.4.3 First prototype: Hardware and Software

To develop our first prototype, we searched for an available open-source mobile platform that met our principles and requirements. The goal was to find robust and readily available platform consisting of readily available modules that could ease the development effort while providing a high degree of flexibility in hardware and software.

We decided to focus on platforms which offered low-cost, readily accessible holonomic hardware revolving around single board micro-controllers (e.g., Arduino, Raspberry Pi etc...) and without a predefined surface appearance, but only chassis, wheels and simple casing for micro-controllers and sensor (in line with requirements TR₁, TR₂). We selected a fully customize do-it-yourself omnidirectional wheel chassis kit ² and an open-source omni-wheeled drive software ³ by Wicked Device LLC ⁴ a technology start-up in Ithaca, New York (United States).

Hardware-wise, the kit consisted off one round acrylic base (Acrylic sheet, 1/8 inch nominal thickness (0.118 inch), about 12 inch for 24 inch), tree ominiwheel sized disks to attach the wheels, six Axle mounting disks to attach the wheels to the motors and three Cat trak transwheels. This 2 inch OD transwheel has synthetic rubber coated polypropylene non-slip

² <https://shop.wickeddevice.com/product/omniwheel-disk-and-wheel-hardware/>

³ <https://github.com/Zagadaga/OmniWheelControl/blob/master/README.md>

⁴ <https://shop.wickeddevice.com/>

rollers, perfect for small robots able to hold up to eleven kilograms. The three wheels mounted on a round chassis (the acrylic sheet) at different angles: zero degrees, one hundred and twenty degrees and two hundred forty degrees. We added a micro-controller board called Arduino Uno, three gearhead DC motors, a battery holder for four AA batteries, a motor-shield, a radio controller receiver (OrangeRx R615 Spektrum/JR DSM2) and a radio controller transmitter (Turnigy TGY-9X). The Arduino Uno is a microcontroller based on the Microchip ATmega328P programmable in the C/C++ language. The board is equipped with sets of digital and analog input/output pins that may be interfaced to various expansion boards and other circuits. DC motors are readily available rotary electrical motors that converts direct current electrical energy into mechanical energy. The motor shield is an additional micro-controller to connect to the Arduino Uno. It controls up to six independent motors, in terms of speed, direction and breaks. It enables pulse-width-modulation outputs (PWM), a technique to translate digital electrical input in analogical outputs. Plus, the motor shield allows to connect a radio control to the Arduino Uno, i.e, it has radio receivers inputs to Arduino. In line with requirement TR7, the holonomic platform is fully controllable. The radio transmitter and receiver enable to control the motors. The radio control transmitter creates signal pulses which the Arduino reads and converts the R/C signals to PWM motor drive signals to actually move the motors. By moving the throttle of the radio transmitter forward, backward or side ways the wheels move accordingly.

Software-wise, we implemented an already existing Arduino library designed for the do-it-yourself kit. In the Arduino code, the radio signals are converted into PWM signals. Next, the Arduino sketch applies vector math formulas to break the motor signal's single vector into 3 vectors, one for each wheel (w_1 , w_2 , and w_3). The wheels moves on vector lines. The line lengths represent the speed of each wheel (WS). The speed of the wheels is the the magnitude of the vector, the direction of the wheels is the vehicle angle, or θ and the angle of each wheel on the vehicle, set a 0, 120, and 240 degrees. Therefore, the Arduino code calculates the length of each vector:

- $v_x = \cos(\theta) * \text{magnitude}$ (cos=cosine)
- $v_y = \sin(\theta) * \text{magnitude}$ (sin=sine)

And then, the code calculates the angular velocities for each of the three wheels. The first wheel moves parallel to the x-axis:

- $w_1 = -v_x;$

The other 2 wheels, w_2 and w_3 , have a component of both x and y axis:

- $w_2 = 0.5 * v_x - \sqrt{3/2} * v_y;$
- $w_3 = 0.5 * v_x + \sqrt{3/2} * v_y;$

Depending whether the results are negative or positive the code optimizes them, because negative values signal to “go backward” and a positive “go forward”. Maximum speed is 3 kilometers an hour (in line with requirement TR5). In line with requirement TR4, the omni-wheel platform affords holonomic locomotion which re-calibrate trajectory, orientation and speed.

We assembled the hardware in the kit (See Figure 47 and the software. We tested the omni-wheel system and implemented the code further to replicate the actions and motion styles with high fidelity.

6.4.4 First prototype: Implementing the Robothing's Behaviors

After having chosen hardware and software, we implemented the code to control the robot to replicate actions and motion-styles. We focused on parametrizing the motion-styles, as they must be constant in every environment and interaction context. Actions are remotetly controlled with the radio transmitter

Therefore, we formalized the sine-wave and jerky path shape to translated it into code. The path shape is the linear (straight motion-style), broken (jerky motion-style) or sinusoidal (sine-wave motion style) motion from a starting point A to an end point B. While the linear path is easily controlled with the formulas explained in the previous section, the sinusoidal and broken path need to be formalized.

First, we enable three modes in the transmitter, one for each motion-style. In so doing, we made sure to lower errors in the remote control of the platform. In channel one, we parametrized the sine-wave motion style. We define the speed of oscillation from left to right, as well as the amplitude of the sinusoidal curves, which we set at three hundred degrees angle. The resulting formula for the sine-wave motion-style angular velocity is:

- $\text{AngularMotion} = \text{Amplitudeofrotation} * \sin(\text{timeinseconds} * \text{speedofoscillation});$

In channel two, we parametrized the jerky motion-style. The jerky motion-style path is delivered as a broken path. The platform drives back and forth to render this motion. Therefore, the direction of motion (i.e., back and forth) changes at defined intervals). Every time the tranmitter input to drive forward (i.e., `vy` in the code) the omni-wheel platforms drives first back (magnitude motion minus 300 in the code) and forth (magnitude motionplus 800 in the code). The code (in C++) is the following:

```
float magnitudeMotion = 300+300*sin(s = number of time the robot goes back and forth);
if (vy <= 0) magnitudeMotion = vy;

if (vy > 0 && magnitudeMotion < 100) magnitudeMotion = -300;
if (vy > 0 && magnitudeMotion > 300) magnitudeMotion = 800;

setMotors(magnitudeMotion, 0, vx);
```

Finally, in channel three the motion-style is straight, therefore we did not apply any implementation to the existing code. Overall, we have implemented the existing software to account for the motion-styles. We tested

how well the implementation works after having defined the form of the robot.

6.4.5 *Exploring a Robothing Form: Design Metaphor, Sketches and Prototyping*

In design research, a **design metaphor** encapsulates the visual, material, and social inspiration to develop a product or, in our case, a robothing [59]. Therefore, a metaphor for a robothing's form needs to be fitting with the interaction we envisioned and consistent with design principles and technical requirements.

In cHRI, the predominant design metaphor is striving towards a human-like (i.e., teacher, coach, peer, mediator) and utilitarian (i.e., maximizing happiness and well-being) social robots. As we know from Chapter 2, these metaphors have the advantages to achieve social engagement. However, these metaphors often cause mismatch of expectations and deception. Therefore in line with our conceptual framework, we chose to focus on alternative metaphors for robothings. We focused on playful interactions striving towards thing-like interactions with toys. To this end, we carried out a visual research of toys you can pull or push made from any material (wood or plastic) and any form and mobile robots for children designed for playful interaction.

We retrieved more than thirty-five non-commercial images and twenty academic images of products, toys, and robots falling within our criteria. We inspected the corpus and deleted double images or images with similar products. Ultimately, our corpus of images consisted of twenty images. Then, to make sense of the corpus of images we clustered them within a four Cartesian quadrants: from **abstract** to **concrete**, and from **non-anthropomorphic** to **anthropomorphic**. These categories have been used before in HRI [70, 18] to characterize the design of artificial agents and clarify the underlining design metaphor of their embodiment. While the non-anthropomorphic / anthropomorphic dichotomy is self-explanatory, the abstract and concrete dichotomy needs more explanation. Different levels of abstraction influence the human perception of a robot's interaction affordances. For example, an abstract humanoid robot and a geminoid robot share the same anthropomorphic metaphor; However, humans will perceive them as differently capable because of their different level of abstraction [70]. Figure 48 show how we systematize the 20 images in

We reflected on how each image reflects design principles and technical requirements. We focused mainly on the non-anthropomorphic quadrants as they are consistent and coherent with our design vision. The non-anthropomorphic and concrete quadrant better represents the principles of form/behavior/function adherence and familiarity, while the expectations balance is weak. The products in this quadrant often reference existing objects or things (say a car or bulldozer truck) and still carry some anthropomorphic cues. Non-anthropomorphic and abstract quadrant better represent

Figure 48: The figure shows the twenty images of products, toys and robots we selected to get inspiration for the design metaphors. The images are systematized in Cartesian quadrants. The x axis go from abstract to concrete embodiment, the y axis from non-anthropomorphic to anthropomorphic embodiment.

the design principle of expectations balance due to lack of anthropomorphic cues. Both quadrants met our technical requirements. Given these considerations, we select a design space between the concrete and abstract quadrant.

We reflected on the design space, our goals and the robothing behavior. Our resulting design metaphor is a pushing wooden toy. The toy as a mix of abstract (its body) and concrete shape (a shovel). Despite the lack of anthropomorphic cues such as eyes, the toy has a clear front and back. It does not resemble the stereotypical embodiment of a robot, and it does not show any digital features. We used this metaphor to develop the form of the robothing. We imagine a wooden toy moving in the space and pushing things around. The body of the robot could remind the one of existing wooden toys. Yet, the shape of its body are dictated “almost molded” by the movements the toy affords.

Through sketching, we visualized the design metaphor. Sketching is a method from design research exploring the visual form of products and supporting tangible prototyping; the sketches were the basis for a tridimensional prototype that we 3D printed.

Two researchers made a series of sketches embodying the design metaphor we selected. First, we started from simple geometrical two-dimensional shapes (Figure 49 a). We distinguished a body covering the holonomic platform and a non-actuated shovel to aim and push objects. After that, we iterated on tridimensional shapes (Figure 49 b). We strived for a form that would not alter the locomotion path but blended with the actions and motion-styles. We reflected that the shape should not wholly occlude the wheels and be as aerodynamic as possible, not to add too much weight on the holonomic platform. Finally, we selected a smooth trapezoid-like shape with a sleek frontal shovel. The sketch embodied the mix of non-

Figure 49: In the figure, two dimensional and tridimensional sketches of the outer-shell appearance.

Figure 50: In the figure, the final tridimensional sketch of robothing's surface appearance.

anthropomorphic abstract and concrete features that we identify in our design metaphor while being a lightweight casing for the holonomic omni-wheel platform.

We rapidly translated the sketches in a tridimensional representation (see Figure 50). We used an online computer-assisted design (CAD) software

Figure 51: In the figure, the 3D model of the body covering the holonomic platform, hence the outer shape of our robothing prototype. The casing on the holonomic platform is visible below the outer shape, blue in the figure.

Onshape ⁵ to design a tridimensional model to be produced (See Figure 51, Figure 52, Figure 53). Finally, we used rapid additive manufacturing (3D printing) to build the first tridimensional prototype with an open-source 3D printer called Prusa. We used a polylactide, thermoplastic polyester (PLA) to print the form of the robothing. The resulting shape of the robot has an area of 83650 millimeters square. It is 225.5 millimeters high and 256.8 millimeters wide. The shovel is attached to the main body, and it is 169.4 millimeters tall and 348.4 millimeters wide. The shape has a hole to accommodate the omni-wheel holonomic platform.

Overall, we defined a design metaphor to guide the development of the robothing surface appearance. After selecting and analyzing related products and robots, we identified a non-anthropomorphic wooden toy balancing abstract and concrete features as our guiding design metaphor. After two and tridimensional sketching, we 3D printed the prototype to test it. As such, the “form” of the robothing consist of the holonomic omni-wheel platform (hardware and software) and the non-actuated outer-shell with a shovel, we designed from our design metaphor.

6.4.6 Technical Tests and Second Prototype

We assembled our prototype consisting of the holonomic platform and outer shape with the shovel (See Figure 55 and Figure fig:internal). To assess how well the prototype performed in various conditions (i.e., different floors, pushing different objects), we carried out technical tests. The technical tests informed our second and perfected prototype.

First, we tested how robust the prototype is, checking how well it drives in various conditions. We tested both simple driving and robothing’s be-

⁵ <https://www.onshape.com/>

3D model casing

Figure 52: In the figure, the 3D model of casing of the honolomic platform.

3D model shovel

Figure 53: In the figure, the 3D model of the shovel of the robothing.

haviors. The tests consisted of patrolling long corridors with our prototype, performing actions, and motion-style on a different floor (wooden, marble, and carpet), various slope degrees, and different objects. Despite being secured on the acrylic base, we noticed that the inner casing containing the Arduino board, motor shield, batteries, and R/C receiver often fell out of place, with wires getting entangled omni-wheels. We observed that the prototype could drive on various surfaces and slopes, but that carpets impaired velocity and stability. Small and medium objects (see Figure) could be pushed without much re-calibration of the trajectory; thus, the prototype performance satisfies technical requirement T4. Solid objects (e.g., wood,

3D model outer disc for the case

Figure 54: In the figure, the 3D model of the additional outer disc of the holonomic platform casing.

plastic, carton) were easily pushed instead of less solid objects (e.g., plush toys).

We have then tested how long the batteries would last and the driving performance at various battery levels. We observed that the platform drained the battery pack quickly, hindering the accuracy of the behavior. Subsequently, we tested how the resulting form of the robothing affected the perception of the behaviors. We asked researchers in the laboratory to observe the actions and motion-styles as rendered by the prototype. While most of the actions and motion-styles are expressed as expected, we observed that the shovel slightly fell off its placement. The shovel's misplacement was due to its constant friction with surfaces and the motor vibration's impact on shovel stability. The shovel instability negatively impacted the prototype's performance, primarily when exhibiting the jerky motion style. Lastly, as per our technical requirements (TR5, TR6, TR7), we tested the prototype's safety. The control of the prototype is easy enough to make sure to guarantee safety. The speed of the robothing is sufficient to push objects but slow enough for a child to be able to touch and stop the robothing while it is driving. We observed it is even possible to stop its motion just by picking up the robothing. Thus, the safety requirements are satisfied.

In light of the technical tests, we iterated on the prototype. To improve the performance in various conditions and avoid casing issues, we designed a sturdier casing for the micro-controllers, wires, and R/C receiver. We designed a bigger disk to encase all the hardware firmly (See Figure 54). We added a higher closure to the casing to allow for ventilation and a seamless connection with the outer shell. We improved the connection between the shovel and the outer shell to make it more resistant to vibrations and friction. We 3D printed the casing with the same producer of the outer shell. The

Figure 55: In the figure, a picture from the technical test of the first prototype

Figure 56: In the figure, a view of the internal casing of the roboting prototype, the hardware and wheels.

battery pack was substituted with a lithium battery and added a boost converter to afford more voltage and higher safety.

As a result, we generated a second prototype improved according to our technical observation. We 3D printed the second prototype and tested again to check whether our improvements worked. Tests were positive; thus, we finalize the second prototype to continue our design process.

6.4.7 *From Behaviors to Form: Conclusions*

This section has detailed how we have translated the building blocks of the robothing behaviors into form, defining the robothing hardware, software, and surface appearance.

This section's outcome is a functioning remote controlled prototype of a robothing, embodying the behaviors children have designed in the co-design workshops. We needed to replicate children's design and generate hardware, software, and surface appearance in line with actions and motion-styles. Translating immaterial behaviors into a specific form was challenging, requiring many iterations and constant reflection in the design process. While we did not discuss the form of the robothing with children, we worked to develop a consistent form with the behaviors designed by children and with our design principles. With this prototype, we proceeded to hone-in the interaction design.

6.5 INTERACTION DESIGN

This section breaks down the envisioned interaction between the robothing and the children and defines the interaction scenario for our play-tests. Much of the interaction was defined during our co-design workshops and crystallized in our design vision. At this stage, we make the interaction concrete.

Scenario-wise, we based our initial design process on the scenarios children explored in the co-design workshop (Chapter 5). At this stage of the design process, we iterated on the scenarios from the co-design study. We incorporated children's consideration and observations to improve the scenario and make it actionable with our robothing prototype. Based on children's reflections, we sketched a conflict scenario in collaborative play exemplary of the child-robothing interactions we envision. Then, we hone-in the interaction flow for the scenario. We specify when and how the robothing's behaviors are delivered in a behavior flow. The behavior flow guarantees a consistent and coherent remote control of the robothing. To conclude the section, we reflect on the resulting interaction design and its limitations.

6.5.1 *Child-Robthing Interaction*

In our design process, we envisioned playful child-robothing interaction based on actions in the game. We have defined how the robothing should interact with children in our initial design process when engaging in co-design with children. At this stage of the design process, with the robothing prototype's availability, we hone-in child-robothing interactions to make

them more concrete. We define the type of interaction, how the interaction unfolds, and reflect on potential interaction modalities and situations.

The robothing has a **direct interaction** with children, which happens in a shared space (Principle of Shared Space). The robothing does not act in the periphery of children's attention, but right in the foreground. The robothing prototype communicates in a specific context, i.e., games. The robothing is not the game's focus per se but is an actor in the game. The robothing communicates only through driving in the space (locomotion) and moving objects in various directions. The behaviors underline the overarching intervention level, promoting prosocial behaviors reciprocity and children's reflection about how to behave in the game. Most of the interactions consist of giving objects, taking objects, and sorting. The child-robothing interaction unfolds over time as transaction, a **turn-taking**, which is consistent with our ideas of having **bid-sequences** of interaction (See Chapter 2, 3, 4, 5).

The child does not control the robothing, but it is **remotely controlled** by the researcher; at the same time, the robothing does not determine how children would behave. It only intervenes in particular situations. In so doing, children retain their agency in the game; they are not guided by the robothing, they can continue or stop playing as they please. The robothing only intervenes in certain instances.

The actions layered with motion-styles embody the **social communication** of the robothing, which does not have any other cues or social affordances (i.e., no distinction between functional and expressive motion). The robothing grounds subject and objects while orienting its locomotion. The shovel is a clear indication of the front and back of the robothing and supports the grounding of communication. Moreover, the shovel is the main object manipulator that pushes objects in the space. Besides driving back and forth and the three behaviors consisting of actions and motion-style, the robothing does not exhibit other behaviors and does not engage in any other interaction. We imagine the robothing responding to collaborative play dynamics, such as conflicts, exhibiting prosocial, antisocial, and passive behaviors. However, the robothing does not respond to any other behavior of the children. For example, should the children address the robothing verbally, the robothing would not react; should the children push the robothing away, the robothing would stop. We decided not to add any additional behavior to focus only on the behaviors we wanted to test and evaluate.

The robothing interacts with multiple children (two of three), but not at the same time. Thus, the robothing addresses a child at a time or two children simultaneously, but it does not engage in complex multi-party turn-taking. The robothing intervenes to diffuse a situation or promote prosocial behavior in a situation, but it does not target a specific child or a specific child's behavior. On top of the technical limitations, we wanted to guarantee that the robothing would exhibit behaviors that could realistically be implemented in an autonomous robothing. The current advances of

social signal processing, perception, behavior planning, and reasoning do not allow a robot such a complex interaction. Therefore, we focused on the realm of the possible to minimize deception (per the Expectation Balance design principle).

The robothing does not afford any other type of interaction. It does not have any other modality, such as sound, lights, or any other actuation. We reflected that as the interaction with children unfolds, haptic interaction might arise. During the turn-taking, the give and take of objects, children could touch the robothing, but the robothing does not have tactile feedback or other bodily sensations to perform actions or processes. The lack of additional modalities is in line with our framework and scope.

All in all, the child-robothing interaction is direct and in the foreground. The interaction is limited to give and take turn-taking, bids of social communication that underline the robothing's intervention in collaborative play. The child-robothing interaction could be enriched in the future with additional modalities, behavior patterns, and sensing. However, we leave this to future research. Even if beyond our research scope, we anticipated that future iteration on the prototype could integrate haptic feedback and other modalities to make the interaction richer. We considered the haptic possibility in our play-tests.

6.5.2 *Scenarios*

Scenarios are used at various stages of the design process to define possible interaction and social dynamics. Children co-design the movements and behaviors of a robothing in given written scenarios. The scenarios children were asked to enact derived from our conceptual framework and observations during our studies (See Chapter 3, 4, 5). These scenarios were instrumental in co-design non-verbal behaviors with children, thereby enabling children's reflections about a robothing's agency in collaborative play. We elaborate on these scenarios after distilling the robothing behaviors and designing a robothing prototype stemming from them.

From children's reflections after the co-design workshop, we gathered the following considerations that we take into account in the scenario generation:

- **Focus on a conflict interactive situation:** Children described the intention of the robot as strategic actions to intervene in the game (which, to a certain extent, is in line with the literature we presented in Chapter 2). While most children described the sharing behavior as helpful and prosocial, children described the hindering behavior with ambivalence. They considered hindering behavior as mean and antisocial and described it as a coercive way to solve collaborative play conflicts. Similarly, the sorting behavior which we deemed to exemplify a passive intention was described as being either unobservant or indifferent. It follows that we should devise a scenario that better promotes the

Figure 57: The figure shows a drawing of the envisioned scenario. Two children are engaged in a Tangram puzzle game with the robothing.

legibility of the robothing's intention by clarifying the reason for the robothing to intervene while leaving some room for children to make sense of the interactive situation in their term. We decided to focus on conflict scenarios between children and define a clear set of actions that will lead to the conflict.

- **Facilitate open-ended construction of meaning in the scenario:** During the co-design workshops, children motivated the robot's actions with imaginary narratives about the fictional children in the scenarios. Originally, we did not give children any description of the fictional children in the scenario besides their names. However, children endowed fictional children with intention and social qualities such as being collaborative, being nice, or -conversely- being nasty and unhelpful. We infer that children will read and interpret what children will do in the situation to grasp the interaction better. Thus, this needs to be taken into account. The scenario needs to be specific enough to create a clear, interactive situation and open-ended to leave space to the children to understand the meaning of each others' and the robothing's actions.
- **Define a neutral narrative for the robothing** Children described the robothing with social qualities that influence its behavior: for instance, as nice, bossy, not caring depending on the interactive situation. Thus, children built a character of the robothing to justify why the robothing would do a certain action in the game. Considering the high variability of children's narratives, we did not apply a specific character or social quality to the actions and motion-styles that we have distilled. Still, we should consider children's tendency and make sure that the scenario offers a neutral narrative for the robothing. Ultimately – in line with our goal and conceptual framework – we want to make sure children will reflect on the robothing's behavior without any *a priori* priming.

We took these considerations into account to iterate on the scenario. First, we defined the scenarios (similar to what we did in Chapter 4). Then, we composed a written scenario (See Figure 57), illustrated by simple vignettes (See Figure 58). Below, we detail the elements of the scenario:

- **Actors in the scenarios:** Similarly to our previous scenario, the actors are children from 7 to 11 years old playing together with one robothing. Like the co-design scenario, two children play with the robothing. We predefine neither the age nor the gender of the dyad.
- **Robthing intervention in collaborative play:** As discussed above, we decided to focus on a specific facet of collaborative play, namely conflict resolution. In line with the co-design workshop scenarios, we focused on conflicts around the possession of objects. To make the interactive situation clear and concrete, we decided to concentrate on a fairly well-described conflict literature phenomenon: conflict arising due to scarcity of resources. To facilitate open-ended construction of the meaning of the scenario and not impose a particular narrative about the robothing, we decided to focus on eliciting a potential conflict in a game manipulating game mechanics rather than the robothing behavior. Moreover, we decided better to specify antisocial behavior as a coercive strategy. Children mainly have interpreted the hindering behavior as a strategy to strongly influence children to stop conflicting about the possession of an object by taking away objects. Therefore, we take this interpretation for our scenario.
- **Collaborative play activity:** We devised a collaborative play activity revolving around sorting objects that landed itself well to conflict elicitation. We focus on Tangram's game, a dissection puzzle consisting of seven flat polygons, called tans, which are put together to form shapes. Tangram puzzles can be played collaboratively or independently. Tangrams are usually made on the floor from example cards showing a specific form (e.g., a cat, a house, a bird, or a boat). The geometrical shapes are usually shared or pushed around by children making them ideal for our purposes. We defined a conflict elicitation game for the scenario. In the game, dyads of children play independently, but share resources (i.e., Tangram pieces) and play in a shared space. Both are asked to make the same shape of a given figure, but they are faced with a scarcity of pieces: at some point in the game, both children need the same puzzle piece, but only one is available. We implemented specialized game mechanics to create a scarcity of resources.
- **Child-robothings interactions and dynamics:** As in previous scenarios, the robothing is a part of the Tangram game with actions such as sorting, giving, or taking objects. We expect the robothing to be playing independently up to the moment in which a conflict is elicited.

Figure 58: The figure shows a drawing of the envisioned dynamics in the scenario as well as the robothing's actions.

The robothing should then intervene with an action delivered with the motion-style. When facing a scarcity of resources, children might fight over the remaining piece of the puzzle. After interacting with the robothing, we expect children to feel compelled to help each other or play independently. The robothing's actions might defuse the situation and invite children to collaborate.

With these elements in mind, we detailed the following written interaction scenario:

"Two elementary school children, Laura and Jim are in a playroom at the school. They want to play puzzle games and they choose a Tangram game. The Tangram game can also be played with a robotic toy that also does the puzzle. The children make a heaps of puzzle pieces in the center of the room. To play the game, each player needs to complete a given puzzle outline with the available puzzle pieces. The robot toy can do the same. The children and the robot sort and select puzzle pieces to be placed on the outline. At some point in the game, there are not enough triangle pieces for Laura and Jim. Therefore, they cannot complete their outline. The children start to discuss who should take the last available puzzle. At first, the robot toys keep doing its puzzle and does not intervene in the discussion. Then, the robot toy sorts its pieces around and select a triangle. It drives towards the children with the triangle, and it leaves it in front of them and then returns to its position. When the children start to fight over the puzzle piece, the robot toy drives towards the children and pushes the puzzle piece away from the children. The children stop fighting and continue playing this time sharing puzzle pieces".

The above scenario is a narrative representation of the actors, intervention, collaborative play activity and child-robot interaction. We use the above scenario (See Figure 58 for a sketch of the scenario) to formalize a flow of behavior and create a narrative context to play-test the robothing and subsequently evaluate the robothing's behaviors and their effects on collaborative play with children. The robothing we designed is a remote-controlled platform. Therefore, we need to formalize how robothing's behavior flow in the interaction. The script of the behavior flow is instrumental in consistently controlling the robothing. On top of the actions and motion-styles we have already discussed, we added simple driving behavior to drive backward after the giving, taking away actions.

6.5.3 *Interaction Design: Conclusions*

In this section, we detailed the interaction design of our prototype. We honed-in the child-robothing interaction and scenario to make them concrete and actionable.

The outcome of this section is a concrete scenario to elaborate the child-robothing interactions. We define a conflict elicitation narrative that is potentially open-ended and defines a neutral narrative of the robothing.

The interaction design is thus focused on evaluating our design vision and conceptual framework. As a result, there are several limitations. First, the interaction design is geared towards short-term interaction. We described interactions that unfold over-time, but do not go beyond one of two sessions. We anticipate that other scenarios with different tasks could be suitable to test the robothing, but we do not explore this possibility in the dissertation as our goal is to design a research platform rather than a product.

6.6 PLAYTESTS AND FINAL DESIGN

Playtesting is used in HCI research and industry as a way to test the usability and experience of a product before bringing it to the market. It is not as rigorous as empirical usability and user experience testing, but it does provide in-depth qualitative insights to developers and designers. It usually consists of sessions in which people freely use or experience an artifact of a game to reflect upon the way it works or other dynamics/features of interest.

We play-tested the robothing prototype and the interaction scenarios with adults and children. In this section, we summarize the insights regarding the play-tests and detail how we improved the robothing and implemented our prototype accordingly.

Figure 59: The figure shows a picture from one of the play-tests sessions with adults

6.6.1 Play-Tests

To play-test our prototype, we invited eight colleagues ($m = 22.5$ age, six females) and ten children from 8 to 13 years old ($m = 10.5$ age, five females) to play with the prototype. All participants are from the east of the United States of America. We recruited the adults through word-of-mouth, while we recruited children during co-design workshops organized at Cornell University. Children and adults were informed that the robot is not autonomous and gave consent to participate in the play-tests. Children's legal guardians were asked to approve children's participation in the play-tests.

The procedure was as follows: We asked both the adults and children to reflect out-loud during and after the interaction about (i) the perceived interaction affordances of the prototype, (ii) the legibility of the robot's behaviors (ii) whether their expectations about what the robot does and how it looks like are met.

The adults and children sat in a dedicated space in our laboratory and played the Tangram task with our robot prototype. Both adult and children play-tested the robot in couples. We followed our scenario: the robot showcased all three behaviors, each with related motion-style. Play-tests lasted ten minutes; after that, participants were asked to think-aloud about the interaction. We took notes of the participants' reflections, but we did not video-record the interactions. We took pictures of participants if they gave consent to it (see Figure 59). We transcribed and reflected our notes and looked for emerging patterns.

Adults found the prototype's affordances to meet their expectations. A participant stated: *"It was clear to me what the robot is from the way it looks like"*. Another said: *"The robot pushes things around and try to sort them out. The shape is unusual, but I can tell what this robot is for. It is a playful fella!"*. Two

adults thoughts that the robothing could have a more straightforward way to express the direction is going. A participant stated: *"The robot is moving quite smoothly, and it looks like a sorting vacuum cleaner. However, it moves too much in a circle, and I do not understand where it is going."* All the adults found the sounds of the DC motors not only disturbing but also misleading. The consequential sounds, i.e., the inherent sounds of moving mechanics, appear to cue affordances, such as being unable to push an object or move around. A participant explained: *"I guess the sound I hear is the sound of the motors, right? I am interpreting as if the robot is not able to do an action because it is so loud and strident, like a car that is malfunctioning"*.

In terms of legibility of the robothings' behavior, all the adults could read the intention of the robothing as we intended it to be. A participant stated: *"I can tell that the robot is trying to give me a piece that I need. When the robot takes the piece away, it is less clear why it is doing that, but I can make sense of it from the context, so, uh, I guess it is trying to tell us to stop or something"*. However, participants commented on the livability of the interaction scenario. Participants thought that the conflict elicitation task was not straightforward, and they did not know whether they were experiencing conflict or not. A participant explained: *"I mean, we are confronted with a lack of puzzle piece. It is not a big deal to conflict about unless we would compete. Maybe for kids, it might be different"*.

Children found the prototype's affordances to be unclear. The fact that the shovel covers much of the robothings' front, occluding the wheels' view, made it difficult for children to understand what affordances the robothing has. Most children (7 out of 10) thought that the shovel was actuated and moved by itself. A child explained that the shovel *"vibrates and moves to eat the pieces of puzzles"*, another stated *"it is unclear to me if the robot uses the shovel to move or it has wheels."* However, they found the behaviors mostly legible and the conflict believable. All the children understood the intention of robothing behaviors. Children expanded on why the robothing would do what it does. A child explained *"I think the robot needs to push stuff and help other children push things right, I am going to call him Push-one"*. Another child described the robot's passive intention as: *"The robot is minding its own business, it does not care anymore. It's done."* The jerky motion style was often confused with technical malfunctions. Seven children out of ten asked the researchers whether the robot was *"about to stop working"* or *"skittering because it does not work well anymore"*. In terms of expectations, half of the children expected the robot to have more functionalities. They consider the robothing as a technological gadget rather than a wooden toy. Therefore they expected more interaction modalities and functions. When asked to explain what makes the robothing look like a gadget, the children explained that the color of the robothing and the 3D printed shell's texture remind them of robotic gadgets rather than regular toys. The other half of the children did not expect much more than puzzle making capabilities.

Overall, thanks to the informal play-tests, we gather insights to help us improve our robothing and interaction design prototype. While our design sorted the desired effect and it is mostly legible, we need to improve: (i) the way the robothing's motor sound, (ii) the color and texture of the robothing embodiment, (iii) the placement of the shovel (iv) the jerky motion-style delivery and (v) the scenarios.

6.6.2 *Final Design*

Building upon the play-test insights, we iterate on the robothing's embodiment, behaviors, and interaction design.

From a technical standpoint, we made the jerky motion-style smoother. To this end, we lowered the number of back and forth movements. In this way, the fidelity with the children's design is kept, while the movements appear smoother and less skittering.

From an embodiment standpoint, we decided to iterate on the robothing shell. First, we made the shell lighter, lowering the PLA density. Then, we fixed the shovel more closely to the front of the robothing, in such a way that it gets less subject to vibrations. We changed the inner-case to make it wider, making the wheel more visible and muffling the DC motors sound. Lastly, we sanded and painted the shell. To be in line with our design metaphor, we examined the predominant wooden toy colors. Typically, wooden toys have a neutral wooden color (e.g., oak, walnut) or painted with primary colors. As it is challenging to render wooden colors on 3D printed materials, we opted for primary colors (i.e., red, yellow, blue). The robot's shell was painted light blue, the shovel bright red, and the sides of the robothing were painted pale yellow. We used matt colors to render a painted wood feel.

From an interaction design point of view, we decided to break the scenarios in three: one scenario in which the robothing gives an object, one scenario in which the robothing takes away an object, one scenario in which the robothing.

Lastly, we adopt the name a couple of children gave to the robot: Push-one. Figure 60 shows the final design of Push-one, a robothing for collaborative play.

6.7 REFLECTIONS AND LESSONS LEARNED

In this section, we reflect on the design process and the design outcomes. We discuss how our chosen approach worked on translating children's design into a proof-of-concept prototype, how well we address our design vision and design principle, and elaborate on limitations.

Figure 60: In the figure, the final version of the Push-one, a robothing for collaborative play

6.7.1 *Reflections on the Design Process*

Co-designing the robothing behavior with children aided significantly in developing a shared movement language to describe the motion of a robothing. However, it was hard to find a method that could retain much of the information children encapsulated in their design. Eventually, we chose the movement centered approach to co-develop the physical form of the robothing and its behavior. The approach gave us the methodological grounds and flexibility to design robots in ways that are not traditionally available to human-robot interaction designers. The process we have followed consists of many iterations and a constant reflection about the design process. Thus, it is laborious, and often it is hard to discern what design decision to take. At the same time, it offers an in-depth meta-analysis of the design process. A continuous assessment of our designs' consistency with the design vision and children's design is of paramount importance.

We opted for a remotely controlled robothing. Hence, we did not work the necessary software and hardware to make the robothing autonomous. The methods and techniques would also work well to design how a robot perceives, learns, and senses to exhibit behaviors. The hardware and software lend itself to design exploration. Still, we anticipate that to design a full-fledged autonomous robothing more alignment between the engineering and the design practices is needed.

Throughout the design process, we questioned whether the design outcomes represent children's ideas on the behaviors faithfully. In our approach, we did not involve children anymore until the end of the process. While many decisions regarding the behaviors follow children's designs, the physical appearance of the robothing was not generated with the children. We opted for a designer-led process to design the robothing's form according to the design vision and principles. We rendered the design vision well even without children's involvement. Still, a children-led design process would have been desirable. To involve children, though, we should have developed an ad-hoc method to design the embodiment of a robothing, which was beyond the dissertation's scope. The challenges we experienced in the design process suggest a few avenues for future work for extending the involvement of children in the design of robot platforms. We think that the techniques we used to select and assemble hardware and software could be accessible to children. Still, they need to be attuned to children's cognitive and motor development and tested. We believe that the cHRI community should strive to democratize the robot design practices and provide access to children.

6.7.2 *Reflections on the Design Outcomes*

We had two primary design outcomes through our design process. First, we formalize the behaviors children designed into actions and motion styles. Then, based on the behaviors, we developed the hardware, software, and embodiment of the proof-of-concept robothing.

Formalizing the children's design into discrete and actionable robothing's behavior was more challenging than expected. To rationalize children's design and describe the motion-styles, we have used the Laban framework developed by Knight and Simmons [205]. While the framework was useful to translate children's enactments into motion elements, it fell short to find a common language among the designers to make the motion discrete and actionable. We needed to supplement the Laban formalization with more descriptive labels (i.e., sine-wave motion-style, jerky motion-style) and tangible visualizations to reach a collective understanding of the way motion-style take shape.

We suggest translating the Laban Framework into visual or verbal representations helps to rationalize the movements and tighten the language around them, facilitating the design process. Also, in retrospect, we would have benefited from digitally capturing the motion children designed. Future work could improve our behavior. Authoring PeerPlay makes it more accessible to children and enables them to record the motion they design. As described in Chapter 5, our method needs several iterations to help children in authoring behaviors.

Translating robothings behavior into a robothing physical surface was challenging due to the lack of established methods. Instead of using anima-

tion methods, we relied on puppeteering to identify the way the robothing should drive. We think that puppeteering provided us with more in-depth insight and a vivid representation of the behaviors' shape. However, for other researchers to follow suit, more research is needed to establish a consistent process applied systematically.

The design metaphor we developed resonates with our design principles and with the robothing's behavior. However, we faced a lack of cHRI knowledge on robot's embodiments. cHRI has few documented reflections on the design choices taken to develop a robot's embodiment. For instance, in HCI, designers develop annotated portfolios [116] to document and reflect over the aesthetic and user experience facets of technology. In HRI and cHRI, we do not have a collection of designs highlighting why a specific embodiment is chosen over others. In our process, we systematize our visual search of toys and robots according to categories that emerged from the literature. We used a design metaphor to describe the direction of the design. While we think this was a fruitful way to select a design direction systematically, we believe that future work should better document the robot's design to inform the cHRI design process better.

6.7.3 *Lessons Learned from the Play-Tests*

The insights of our play-tests show that it is hard to design for form/behavior/function adherence. One of the premises of the dissertation is that anthropomorphic design and behaviour sets expectations that cannot be met, while non-anthropomorphic design and behavior would set more realistic expectations.

While both children and adults do not overestimate the robothing's capabilities, they still find the robothing's affordances confusing at times. A common denominator between adults and children's impression of the robothing could have more straightforward affordances. We have mitigated this by improving our design according to the play-tests feedback, but this insight illustrates that several iterations are required to get non-anthropomorphic and non-verbal affordances right. Moreover, we learn that not only how a robot look and behave influence children's expectations, but also the stereotypical metaphors of robots might play a role. Children considered the robothing prototype as a robotic gadget because its colors and texture reminded them of those products. Designers should explore further the impact of ingrained narratives or visual imageries.

We learned from the play-tests that consequential sound has quite an impact on how people experience a robot, in line with recent literature on the matter [255]. We did not take consequential sound into account in our design process, but we anticipate that future work should examine the effects of consequential sounds on cHRI and the perception of a robothing's behavior.

The play-tests corroborated our insights from the co-design workshop related to the perception of motion-styles. On top of technical limitations, children appear to apply extra intentional meaning to the motion-styles of the robothing. The context and the sequence in which the behaviors are presented play a role too. Empirical studies should take this insights into account and tease apart the effects of actions and motion-style while controlling for the context.

6.7.4 *General Implications*

Our work articulates in detail a full design process that translates children’s low-fidelity designs of a robothing behavior into a remotely controlled robothing prototype. By bringing together movement centered methods with traditional design methods, we were able to successfully design and formalize a range of behaviors for a robothing that are potentially communicating legibly to children.

Our design exploration session based on puppeteering and sketching proved successful in bridging the gap between free-form exploration during the workshop with the children and the finely controlled behavior to develop the robothing prototype. We showed that implementing the Laban framework with descriptors and visualizations helps find common ground in the design process.

Our process informs designers of non-anthropomorphic robots for children, as it provides an in-depth account of how to make design decisions. Our work is one of the few, with [7] and [235], providing details of the design rationale at every step of the design process. We argue that cHRI, as a field, should focus on reporting how robots are designed and what design decisions are taken in the process. We have noticed that the lack of methods, tools, and techniques makes it hard to develop robotic technology for and with children.

6.7.5 *Limitations*

We identify some limitations in our design process and design outcomes. First, we focused on simple locomotion mechanisms and did not explore the design space of locomotion further. We chose to simulate the actions and motion-styles children designed with readily available robotic platforms. It was a deliberate choice, as we aimed at developing a robothing that could represent children’s design and that is familiar to children. We anticipate that other locomotion types could have been employed, but we deem the holonomic locomotion to be faithfully representing children’s design. Second, we focused on designing a remotely controlled artifact. Therefore, the validity of our prototype is limited to remotely controlled scenarios. Should an autonomous version of Push-one be developed, we

anticipate that slight changes in the behavior and embodiment design might occur. However, we think that the current prototype approximates autonomy in terms of hardware, software, and embodiment. Th

Another limitation is the interaction design scope. We have designed Push-one as a proof-of-concept prototype to use in our research. As a result, it is not a full-fledged product, and we do envision use outside the academic setting. The interaction design is limited to actions, contexts, and dynamics we would like to study. Therefore, our design is not easily applicable in multiple contexts. Our scenarios sketch a minimal set of interactions within the scope of our research. We do not elaborate on multiple encounters with Push-one, and we have a somewhat narrow focus on short term interactions. The interaction design is scripted more than naturally occurring children's interactions because we want to evaluate the effect of the robothing's behavior on children's collaborative dynamics after a conflict. We leave the exploration of more sophisticated, unscripted, and long-term scenarios to future work.

6.8 CHAPTER CONCLUSIONS

In this chapter, we have presented Push-one's design process, a proof-of-concept robothing for children's collaborative play. The chapter has two primary outcomes: (i) we define a set of behaviors from children's designs (Chapter 5) contextualize in conflict elicitation scenarios (ii) we develop a robothing's artifact, Push-one, designed based on the behaviors and our design principles.

The co-design outcomes of Chapter 5 were for us the starting point to design a robothing that communicates to children how children would like it to communicate. To translate children's designs into an artifact, we took a movement centered approach. The work presented in this chapter articulates in detail a full design process that translates children's low-fidelity designs of a robothing behavior into a remotely controlled robothing prototype.

Push-one's embodiment follows its function (what it does) and its communication (what it wants to achieve by interacting). The result is an abstract, non-anthropomorphic, non-verbal, animated wooden-toy that assembles geometrical wooden puzzles. Push-one is remotely controlled and mobile; it has holonomic locomotion. It can move in any direction; it has non-reprehensible manipulation. It can push-objects in a specific order to a shovel-like front. Push-one operates specifically during children's conflicts around the possession of objects. By doing so, Push-one operates to stimulate children to reflect on the conflicts and find a way to be prosocial. As a result, Push-one does not tell kids how to behave in conflict. Push-one is designed to enable children's independent reflection-in-action about their prosocial or antisocial behavior in a game rather than dictating how it is right to act.

Our design process and our design outcomes inform designers of non-anthropomorphic robots for children, as it provides an in-depth account of how to make design decisions. Our work is one of the few, with [7] and [209], providing details of the design rationale at every step of the design process.

Within this dissertation's scope, we provide a proof-of-concept robothing artifact – partially designed with children – to continue our research on the effects on robothing's on children's collaborative play. Moreover, we provide a set of scenarios to evaluate the robothing's behavior readily.

The chapter's outcomes inform tangentially two of the research questions in the dissertation, namely RQ2. *How should the interaction with a robothing be designed to impact prosocial dynamics in play?* and RQ3. *How should the non-verbal behavior of low/non-anthropomorphic robots be designed to communicate a robot's intention to children?.* We provide insights on how to design robothing's behaviors. We give extensive details on the process we take to develop a robothing's behavior. We show that an interactive design exploration alternating puppeteering and embodied simulation helps designers shape a robothing's behavior. We give preliminary insights about how to deal with the interplay between the form of a robothing and its action to support degrees of form/behavior/function adherence, thereby communicating legibly to children without raising too many children's expectations. We detail how the interaction with a robothing to intervene in a conflict, thereby promoting prosocial behavior and regulating collaboration, could be designed. Our scenarios and behaviors embody a design vision wherein children reflect on collaboration and prosocial behavior in action, play and retain their agency in the interaction.

Our work has methodological and procedural limitations due to the challenges of designing non-anthropomorphic and non-verbal robothings for children. Throughout the design process, we questioned whether the design outcomes represent children's ideas on the behaviors faithfully. We opted for a designer-led process to design the robothing's form according to the design vision and principles. We rendered the design vision well even without children's involvement. Still, a children-led design process would have been desirable. To involve children, though, we should have developed an ad-hoc method to design the embodiment of a robothing, which was beyond the dissertation's scope. The challenges we experienced in the design process suggest a few avenues for future work for extending children's involvement in robot platforms' design. We firmly believe that the cHRI community should strive to democratize the robot design practices and provide children more access to the design process.

COMMUNICATING CONFLICT-RESOLUTION INTENTIONS IN A ROBOTHING USING LOCOMOTION: THE INTERPLAY OF ACTIONS AND MOTION STYLES

“Our behavior depends on what we perceive the other person’s intentions to be. It is not about the behavior itself but how we perceived their behavior.”

J. J. Gibson (1977)^a

^a I suggest to listen to **Ms. Ho** by Onra and **The Seven Planetary Heavens** by the Comet is Coming while reading this chapter.

Chapter 7 reports a video-based HRI study (Study 5). The study sought to understand how a robothing’s locomotion communicates to children its intention to intervene in a conflict. Study 5 evaluates robothing behaviors, as distilled from the outcomes of co-designing with children (Chapter 5 and Chapter 6). In previous chapters, we have seen that a robothing communicates its intention to children through various action (Chapter 4). Simultaneously, the co-design workshops unveiled how children stylized a robothing’s locomotion to convey extra information about its intention and social attributes. In this chapter, we explore the interplay of actions to intervene in a conflict (i.e., giving, taking, not intervening, expressed through locomotion only) and three motion styles (i.e., linear, sine-wave, and jerky, which are locomotion styles) implemented in the Push-one robothing (Chapter 6). We sought to assess (i) how children interpret and explain the reason for robothing’s actions, (ii) how the behaviors influence children’s perception of the robothing’s helpfulness in the context of conflicts, and (iii) whether children would ascribe different social qualities to the robothing behaviors depending on the type of action and motion style. The chapter discusses findings and design implications.

The chapter is based on the following publication:

Zaga, C., Jung M. F., Truong K. P. and Evers V., It’s all in the way it moves! Communicating Conflict-Resolution Intentions in a Robothing Using Locomotion: The Interplay of Actions and Motion Styles, ACM Trans. on Human-Robot interaction (THRI), (in preparation)

7.1 CHAPTER INTRODUCTION

*Motivation of the
chapter*

When we interact with one another, the “way” we do so communicates as much as our actions do. So far, in our research, we have considered non stylized non-verbal actions only. In our conceptual framework, we posit that the actions of a low/non-anthropomorphic robothing suffice to communicate in “human terms” (Chapter 4). However, co-designing with children (Chapter 5) uncovered how the motion style (i.e., the way the robothing moves) of a robothing’s action (i.e. its goal-directed act) impacts the way children attribute intentions and social qualities to a robothing. When reflecting on each other’s designs, children attributed prosocial, antisocial, and passive qualities to the robot puppet’s movements, depending on the action *and* the motion styles. Children went as far as describing a whole character for the robothing from actions and motion styles only. We have taken the co-design workshops’ findings under consideration to design Push-one, our proof-of-concept robothing (see Chapter 6). Push-one primarily communicates through actions expressed with its locomotion, which affords to be stylized. While the indications from the co-design workshop are promising, HRI literature is wary about the impact of motion styles on HRI communication. Neither consensus nor broader guidelines are available to guide the design of expressive locomotion. Therefore, exploring the interplay of actions and motion style for Push-one is crucial for designing robothing behaviors that communicate effectively to children in collaborative play. Any misunderstandings will hinder a robothing’s intervention in collaborative play.

Overview of the chapter

This chapter explores how Push-one’s locomotion communicates different intentions to intervene in children’s conflict. The chapter reports on the fifth study of the dissertation (**Study 5**), a mixed-design and mixed-method video HRI (VHRI) study. We hone in on the interplay of actions and motion styles of actions. We seek to understand how children read, attribute intention to, attribute social qualities to, and perceive the helpfulness of a robothing’s actions, and whether the motion style impacts in any way children’s understanding, attributions, and perceptions. The chapter contributes to the answers to two of the research questions of the dissertation: namely, RQ3 —*How should the non-verbal behavior of low/non-anthropomorphic robots be designed to communicate a robot’s intention to children?* and RQ4 —*How do children interpret and perceive the non-verbal behavior of low/non-anthropomorphic robots in play?*.

7.2 STUDY 5. HOW CHILDREN UNDERSTAND AND PERCEIVE A ROBOTHING'S BEHAVIOR TO INTERVENE IN CONFLICTS: THE INTERPLAY OF ROBOTHING ACTIONS AND MOTION STYLES

7.2.1 Introduction

Robots with less human-like forms, behaviors, and roles are becoming new avenues of child-robot interaction (CHRI). Low/non-anthropomorphic socially interactive robots look more like abstract toys and behave in straightforward but meaningful ways, enabling playful interventions that can foster children's development: from supporting children's learning [235] and creativity [7] to collaboration [324] and play [299]. A prerequisite for robots that do not bear resemblance with humans is to communicate the intention of their behaviors and actions [333]. Only when communication is clear child-robot interaction lead to the desired social outcomes [105]. A robot's action communicates the intentions of a robot and influences children's perception of the robot and the interaction outcomes. Not only do its actions communicate to children, but how the robot executes them affects the way children understand its intention. Researchers have explored the role of motion styles (the way a robot performs an action) in low- to non-anthropomorphic robots [206, 333]. Studies show that a motion style on top of a non-anthropomorphic robot's task actions influences how people understand the robot's behaviors and attribute intention, social qualities, and other characteristics to the robot [53, 207, 228, 302]. In particular, a motion style appears to modify or increase the communication and perception of an action's intention (e.g., the speed and curvature of robot locomotion (e.g., a Roomba vacuum cleaner) influences the perceived affective state of the robot). However, broader guidelines on how to express a robot's intention using non-verbal actions and how to use motion styles are missing in the human-robot interaction literature in general and in the child-robot interaction literature.

The interplay of a robot's actions and motion style

Research Questions

We tackle these open challenges in HRI for Push-one, a robothing developed to promote children's collaboration in play. We explore how the robothing communicates its intention to intervene (and possibly resolve) only with locomotion a children's conflict over the possession of objects during play. We focus on a robothing's actions (i.e., giving, taking away, not intervening) underlying different conflict-resolution strategies (i.e., prosocial, coercive, passive) that children use to defuse conflicts [248, 319]. We address the following question:

Question 1: *How do children interpret the intention of different robothing actions to intervene in a conflict?*

In previous chapters, we have seen that a robothing communicates its intention to children through locomotion only (Chapter 4). On the other hand, the co-design workshops unveiled how children stylized a robothing's locomotion to convey extra information about its intention and character.

For this study, we want to design a conflict-resolution strategy with minimal behavior. To this end, the robothing uses locomotion to perform its action, onto which we apply three motion styles (i.e., linear, sine-wave, and jerky). We derive actions and the motion styles from our previous work (co-design workshops with children, see Chapter 5) and literature [207]. Our previous work and literature show that a linear, sine-wave, or jerky locomotion on top of actions impacts how children interpret an action's intention and the perception of social qualities of a robothing differently. At the same time, children perceive actions taken to intervene in conflicts differently: they can find actions more or less helpful [248]. But also, children ascribe different social qualities to the party performing the action [97]. However, little is known about how the interplay of motion style and actions affects children's understanding and perception of a robothing's behavior. Therefore, we pose the following sub-questions to the central question of this chapter:

Sub-Question A: *How does a motion style (linear vs. sine-wave vs. jerky) impact the way children interpret different robothing's actions to intervene in a conflict?*

Sub-Question B: *What are the effects of a robothing's motion style (linear vs. sine-wave vs. jerky) and actions (giving vs. taking away vs. non-intervening) on children's perception of helpfulness of the robot?*

Sub-Question C: *What are the effects of a robothing's motion style (linear vs. sine-wave vs. jerky) and actions (giving vs. taking away vs. non-intervening) on children's perception of social qualities of the robot?*

Overview of Study 5

We address these questions in a 3 (conflict-resolution actions, between-subjects) by 3 (motion styles, within-subjects) mixed-method, and mixed-design VHRI study. Our findings show that a robothing's action (giving, taking, not intervening) communicates to children different intentions to intervene in a conflict, impacting both children's perception of the robothing's helpfulness and how children ascribe social qualities to a robothing. The robot's motion style does not appear to have a particular impact on how its actions are understood and perceived. However, we find that a sine-wave motion style interacts with the robothing's actions endowing the actions with prosocial intentions, qualities, and a boost in the perception of their helpfulness.

7.2.2 Background and Related Work

The study is situated in research on conflict-resolution in child psychology as well as HRI studies that have begun to explore how a non-anthropomorphic robot motion communicates a robot's intention, goals and social qualities.

Children's strategies and communication during conflicts

As we have seen in Chapters 2 and 3, children resort to various behavioral strategies [248] to intervene in a conflict. Studies have found that like

Children's ways to
communicate
conflict-resolution
strategies

adults [371, 158], children use prosocial strategies to resolve a conflict (otherwise defined as strategies to help one another) [371, 158]. Children can communicate prosocial strategies both verbally and non-verbally, but they deliver strategies foremost via actions, for example, by sharing an object [248, 319]. Children also use coercive strategies (verbally and non-verbally) to communicate their intention for an argument to stop (otherwise defined as going against one another [371, 158]). Children use forceful actions or micro-aggression to coerce other children to stop an argument during a conflict [248]. Actions like taking an object away forcefully are considered coercive strategies. Passive strategies – otherwise defined as going away from one another [371, 158]– are often used to leave it as is. In other words, children avoid intervening in a conflict either verbally or non-verbally, hoping that the conflict eventually ceases.

Children use conflict-resolution strategies not only to deal with conflict but also to regulate peer relationships. While both prosocial and coercive strategies can end a dispute successfully, they impact the perceptions of and the relationship among peers differently [248]. Studies have found that children who exhibited prosocial strategies were considered likeable and friendly, and hence were more accepted by their peers. Children who used coercive strategies were regarded as antisocial and aggressive: i.e., peers to dissociate oneself from [248, 319, 396]. Moreover, research has found that children who used prosocial strategies influence other children to be more prosocial in future interactions [97].

Effect of children's communication of conflict-resolutions strategies

From the above-described literature, we conclude that the actions of giving, taking, or not intervening are relevant to communicate underlying prosocial, coercive, and passive strategies in conflict. It is crucial to take into account that the strategy embodied in actions can have several implications for the way children perceive one another. While both prosocial, coercive, and passive strategies could resolve a conflict, prosocial strategies have a more positive effect on children's perceptions of their peers, which can have positive repercussions in collaborative play.

Non-anthropomorphic Robot Motion Communication: The Role of Actions and Motion Styles

HRI research is increasingly exploring non-anthropomorphic robot motion to achieve communication with humans [105, 151, 228, 356]. Non-anthropomorphic robots' actions appear to communicate intention. For example, Sirkin et al. [333] found that a robot footstool's locomotion communicates the intention of the robot to approach people. Not only can a non-anthropomorphic robot communicate its intention through actions, but it can also influence adults' and children's perception of the robot and the interaction outcomes. Jung et al. [184] found that an industrial robot arm can shape the perception of fairness, merely by actions to redistribute resources. Fink et al. [105] found that in a tidying up task, a robot wiggling proactively

The role of actions in non-anthropomorphic communication

led children to explore more, while a robot wiggling reactively led to more tidy-up behaviors. Similarly, our previous work (see Chapter 4, Studies 2, 3, and 4) has provided indications that a robothing's motion impacts children's perception of a robothing behavior. Minimal rotations of a robot's base and a robot's locomotion to share, take away, and nudge objects are interpreted as their being animate, likable, and helpful (or unhelpful) by children and thus impact children's reciprocity [412, 415].

*The role of a robot's
motion style in
non-anthropomorphic
communication*

Likewise, a robot's motion style has been found to influence the way people perceive a robot's behavior and the response to robots in HRI. Most of the HRI literature has focused on the expressivity potential of a non-anthropomorphic robot's motion, exploring motion patterns and characteristics that contribute to a motion style. Saerbeck et al. [302], show that the speed and curvature of robot locomotion (e.g., a Roomba vacuum cleaner) influence the perceived affective state of the robot. Knight et al. [207] found that locomotion styles layered on top of a non-anthropomorphic robot's task actions influence how people attribute characteristics or states to it (e.g., being confident or in a hurry). In particular, the authors have found that linear motion is the easiest to interpret. A sine-line motion path helps people realize when the robot knows what it is doing, whereas line-sine movement is challenging to understand.

A robot's locomotion also communicates complex emotional and pro-social/antisocial traits. Cauchard et al. [53] showed that changes in the speed and form of a flying path express signaled not only a drone intention, but also its character and emotions. In particular, the authors found that people see high speeds, spins, and flips as the proactive, happy acts of an adventurer, and they perceived a moderate pace with brief jerky stops as antisocial behaviors. Depending on the motion style, Li et al. [228] found that non-anthropomorphic robot locomotion influences people's perception of the dominance of the robot. For example, people see movement as having a higher status when it is with at fast speeds, directed to the person, and features lifts. Research in child-robot interaction is scarce regarding the influence of a motion style on children's perception of a robot. Our co-design work (see Chapter 5) has shown that children use motion parameters such as motion path and speed, to puppeteer behaviors of a non-anthropomorphic robot. Children use different motion styles to render the robot's character in the interaction. For example, we have observed that children use a sine-wave motion to imbue a puppet robot with collaborative traits, whereas they use a jerky motion to imbue a puppet with aggressive traits.

Building upon these related works, we investigate the interplay between a motion style of a robot's locomotion and a robot's action. Specifically, drawing from the literature and the outcomes of our co-design workshops, we explore the path (e.g., linear, sine-wave, and jerky) of a motion style layered on top of the robot's task actions (in our case actions that underline a conflict-resolution strategy).

Figure 61: The Push-one robot, the robothing of the VHRI study, with tangram puzzle.

7.2.3 *Methods*

In a 3 (conflict-resolution actions, between-subjects) $\times$ 3 (motion styles, within-subjects) mixed-design VHRI study, we evaluate children's perception of the behaviors of a robothing (the Push-one robot). The goal of the VHRI study is to discern how children read, attribute intention to, attribute social qualities to and perceive as helpful a robothing's actions to intervene in conflict scenarios, and whether the motion style modifies the perception of the robothing's actions.

As it was our primary experimental interest, we manipulated the conflict-resolution actions as within-subjects factor (i.e., giving, taking, not intervening) and the motion styles as between-subjects factor (i.e., linear, sine-wave, jerky), to understand if changes in the motion style impact the perception of a conflict-resolution action.

Participants

Ninety children from Ithaca (New York State, United States) (m(age): 9.08; SD: 1.456; 40 girls, 50 boys; 88 American and 2 Mexican nationals) participated in the VHRI study. We recruited participants from online parent groups and after-school programs in the area. We invited participants at the university, or we reached the participants at their after-school programs. Inclusion criteria were the participant's ability to speak, write, and read English. Originally ninety-six children were recruited, but six children

did not finish the survey; and thus, were discarded from the participants' pool. Each participant was randomly assigned to a conflict-resolution action condition, which resulted in sub-sample sizes of $n=30$ linear motion style, $n=30$ sine-wave motion style, $n=30$ jerky motion style.

Ethics

The Institutional Review Board (IRB) at Cornell University approved the VHRI study. The children's legal guardians signed an informed consent form before the study. After being fully informed about the format of the study, the children signed an assent form to participate in the study. At the end of the VHRI study, we debriefed children thoroughly about the scope of the VHRI study. To address issues of deception, we informed the children that the robothing seen in the videos was controlled remotely by a researcher.

Robthing and Robthing Behaviors

The Push-one robot (see Figure 61) is the robothing used in the VHRI study (see Chapter 6 for details about the design of Push-one). Push-one is a remotely controlled non-anthropomorphic robothing developed for research purposes. The robothing communicates only through holonomic locomotion (i.e., it can move in all X and Y directions and is not constrained): Push-one has three omnidirectional wheels and can move in all directions. Besides affording forwards, backward, and lateral motion, Push-one can rotate on its base. Push-one does not have any other modalities but its bulldozer shovel enables it to push objects around while moving on a flat surface (i.e., floor, table).

The robothing's actions are based on literature and from our co-design workshops with children (see Chapter 5 and Chapter 6). The robothing motion styles have been distilled from the behaviors designed by children in our workshops and are in line with the literature (see Related Work).

- Robthing conflict-resolution actions** The robothing exhibits three actions, each corresponding to a specific strategy to intervene in a conflict. The types of actions (giving, taking, not intervening) are identified from literature and from Chapter 6 and Chapter 5. The motion of the action (the way it is realized) derives from our co-design workshops with children. **Giving** underlines a prosocial strategy for conflict resolution: sharing objects to stop an argument over the possession of objects. In our scenario, the robothing gives an object it has to the children by pushing a piece of the puzzle in their direction. The children only have one piece of that kind and are arguing about who should have it. The robothing stops in front of the children with the puzzle piece the children need and then goes back to its position. **Taking** is an action that underlines a coercive strategy for

conflict resolution: forcefully suggesting to stop an argument over the possession of objects. In our scenario, the robothing pushes away the puzzle piece children are arguing about and then goes back to its position. **Not intervening** in a conflict underlines a passive conflict-resolution strategy: to mind one own business in the hope that the conflict will resolve itself. In our scenario, not intervening translates to keeping on playing without taking any action to intervene in the conflict. The robothing pushes its puzzle pieces to do its puzzle.

- **Robothing motion styles** The robothing exhibits three motion styles: linear, sine-wave, and jerky. Each have various influences on the perception of robot actions (See Chapter 2). In the **linear motion style**, the robothing drives forward in a monotone fashion and at a velocity of 1 km an hour. In the **sine-wave motion style**, the robothing drives forward in continuous, sinusoidal curves. We set a fixed amplitude of rotation on 300 degrees with a velocity of 1 km an hour. In the **jerky motion style**, the robothing drives forward in a broken path. In this motion style, the robothing acceleration changes between 0 and 100, resulting in a staggered motion path.

Push-one is a remotely controlled robothing. Therefore, a researcher controlled Push-one with a radio-transmitter controller to realize the above-described behaviors. To guarantee uniformity and consistency of the motion style for each condition, we implemented three modes of control of the radio-transmitter. Each mode corresponds to one of the pre-programmed motion styles. By switching the radio-controller to one of the three programmed modes, the robothing style of motion is on one of the corresponding modes. In doing so, the researcher who controls the robot can control the movements of the robot, but not the motion style. For example, by switching to channel one on the radio transmitter, the robothing would only locomote in the linear motion style, but the researcher could still control the robothing to exhibit different actions. The code of the radio-control and style is available in the Appendix A and on Github ¹.

Figure 62 summarizes the resulting behavior per condition.

Materials: Video Stimuli

The scenario of the video study was as follows: two children, Jim and Laura, are sitting on the floor, one next to the other. Push-one “sits” in front of them. The children and Push-one are playing independently with Tangram puzzles, a geometric puzzle with which one can make various shapes. Children and Push-one need to make a shape by placing some puzzle pieces on a paper outline until completion. The children and Push-one retrieve puzzles pieces from a pile of pieces placed at a central position between the children and the robot. After some time, both of the children

¹ <https://github.com/Zagadaga/Pushone/blob/master/controlandbehavior>

Motion Style: Between Subject conditions	Actions: Within-subject conditions		
	Giving	Taking	Not Intervening
Sine-wave	Giving Sine-wave	Taking Sine-wave	Giving Sine-wave
Linear	Giving Linear	Taking Linear	Giving Linear
Jerky	Giving Jerky	Taking Jerky	Giving Jerky

Figure 62: Details of the within-subject conditions and between-subjects conditions of the VHRI study. The pictures visualize the motion styles.

Figure 63: The pictures show frames from the videos stimuli. Figure a) shows the giving action, figure b) the taking action, figure c) the not intervening action

Figure 64: The Scenario of the Video-Based HRI Study

Figure 65: A frame from the conflict scene in the video stimuli.

need the same puzzle piece, which is the last one available from the pile. The children both reach for the piece and start pulling the piece in their respective directions. Push-one intervenes in the argument with different strategies: it either brings a puzzle piece of its own pile of pieces that has the shape and color children needed; or Push-one approaches the children who let the piece they are arguing about fall and Push-one takes it away from the children; or Push-one keeps on pushing its own puzzles pieces, minding his own business, thereby not intervening.

To shoot the video, we asked a female and male actor to play the “children’s” roles. The actors sit on the floor, in front of the paper outline and the pieces of the puzzle. The robot is positioned on the opposite side of the floor, centered between the two actors. We chose the same camera perspective as [224] and our previous work [411] (see Chapter 4), i.e., over-the-shoulder of the actor (only back, arms and back of the head visible) to minimize the 3rd person perspective [309] effect. Actors trained with the script of the above-described scenario for one week before the video was shot. The actors’ actions are consistent over the videos. The Push-one robot was controlled remotely by an experienced researcher, who trained for four weeks before shooting the videos and one week with the actors. The researcher was outside camera view. Training sessions and retakes guaranteed consistent behavior for all the videos.

We prepared nine experimental videos lasting 27.5 seconds each, corresponding to the nine conditions and one introductory video of 15 seconds to introduce the participants to the interaction scenario. Both videos were shot without audio. In the introductory video, a viewer sees the children and Push-one at the beginning of the game, with the children picking up and placing puzzle pieces from the pile in front of them. At the same time, Push-one pushes puzzle pieces from the pile towards its paper outline. In the nine experimental videos, a viewer sees the children each picking up a different piece of the puzzle and after a while the children simultaneously reach for the last available yellow triangle piece and both tugging at it. After 5 seconds, Push-one intervenes with one of the behaviors. Once Push-one completed the action, the video ends.

Figure 64 shows a frame from the video that detail the scenario. Figure 63 shows the robothing’s actions in the video stimuli whereas Figure 65 shows the conflict moment.

Materials: Survey Design

We designed a playful survey in which we embedded introductory and experimental videos. To assess participants’ understanding of the robot behavior, we designed a survey attuned to children’s cognitive and social development and to their reading and comprehension level (2nd through 6th grades elementary school in the United States, which corresponds to 7 to 11 years old). We accurately follow recommendations of survey developments

for children [242]. For this reason, we make the survey a playful experience for the children.

We designed the survey on the online platform Typeform ². The survey starts with the following call-to-action: *We are building an interactive toy, Push-one, that plays games with kids like you. Ready to become a designer for a day and help us out? Design missions are awaiting! Press start.* After that, the survey asks for the age and nationality of the children. Before starting with the introductory video, the survey explains that there are three “missions” ahead and shows a picture for the introductory video (the text reads as follows: *There are three missions for you. The goal is to understand what Push-one is doing in 3 situations while playing a puzzle game with two kids, Jim and Laura. You can see Jim, Laura, and Push-one in the picture.*). After this introduction, participants are exposed to an experimental video and then to a set of questions. This format repeats three times in random order.

Setup and Procedure

We conducted the VHRI study at two locations, in rooms of the Cornell University and at after-school programs. The experiment rooms were equipped and arranged similarly to avoid possible confounds. Participants saw the videos and responded to the survey on five laptops placed on three tables at a distance of fifty centimeters each. Participants sat in front of the laptop. We blocked the laptop browser on the survey page, and participants could not browse to any other page.

Each study session lasted 40 minutes on average and a maximum of five participants was allowed to participate. In total, we administered twenty-four study sessions in four weeks. To entice participants to take part in our study, we invited participants to a “Robotics day” comprising an experiment and a robotics workshop. First, participants joined the study, and then participants partook in a robot programming workshop with various toy robots. We did not introduce any robots before the study. Parents and caregivers of the participants stayed in the same room with the participants during the study, but we asked them not to talk to the children unless children asked for their parents/caregivers.

Three researchers conducted the VHRI study. One researcher was the leading facilitator of the sessions, the other two researchers (blind to the videos and scope of the study) assisted with participants' questions/needs. After briefly introducing researchers and participants to each other, the researcher-facilitator presented the study as an opportunity for children to give their “expert” opinions about robots. Children wore an “expert-tag” provided by the researchers. We asked the participants to help us understand the behaviors of a robot designed for children: the survey was a “mission to complete”. We invited participants to watch the videos and to respond to questions after each one to complete their mission. Researchers

² <https://www.typeform.com/>

assisted the participants with reading and typing when requested. Researchers were instructed not to suggest any answers to the children nor to correct spelling/grammar/syntax, but only to facilitate them with their understanding of the questions or with typing on a keyboard.

When all of the participants were finished with the survey, we debriefed them about the scope of the study. Moreover, we explained that the robot in the videos was not moving autonomously. We showed the participants the Push-one robots and how we remotely controlled it. After debriefing, participants received a certificate for their participation. After that, participants would start with a robotics workshop with toy robots.

Codebook for Open-Question: Why do you think Push-one did what it did?		
Code	Definition	Examples
Controlled	Responses describe the reason for the robot to do something/ intervene as: it was programmed to do so or controlled by the children in the game to do so	<p>"It was programmed to help Laura", "Cause it was programmed to", "He was coded to do it", "Because the people commanded it to build it", "It was programmed to stop the fight", "because it was controlled by the yellow triangle"</p>
Prosocial	Responses describe the reason for the robot to do something/ intervene as: the robothing wanted to help the children (or one of the children) in the situation, to stop children from fighting, to be nice in the situation	<p>"because he wanted to help" "I think that Push-one did what it did to help Lara and Jim" "because he wanted them to not fight over it" "Because they were fighting and it is nice. It want to help" "To defuse the situation"</p>
Not intervening	Responses describe the reason for the robot to do something/ intervene as: the robothing wanted to mind its own business, the robothing keeps playing with its puzzle blocks undisturbed, the robothing wants to finish its puzzle, the robothing did not see	<p>"To to the puzzle", "because it wanted to finish the puzzle", "I think Push-one did this to avoid any big problem for itself and not get in the middle of it", "because he did not see Jim and Laura fighting over the yellow block!!!"</p>
Antisocial	Responses describe the reason for the robot to do something/ intervene as: the robothing want to steal a block from the children or it wants to get rid of the block because he is annoyed/mad at the children fighting or it does not care	<p>"He does not care", "because he was tired of the children", "because he wants to stealing", "he wanted the block for itself", "because he did not want to help solve the problem"</p>
Positive Attribute	Responses describe the reason for the robot to do something/ intervene as: the robothing reason for intervening in the game is because of its positive attributes, such as being nice, thoughtful	<p>"because he is nice", "Because he is being thoughtful", "it is a nice toy", "because he is kind"</p>
Negative Attribute	Responses describe the reason for the robot to do something/ intervene as: the robothing's reason for intervening in the game is because of its negative attributes, such as being mean, nasty	<p>"because he was being mean", "because he is nasty" "because he was nasty and mad at Jim and Laura"</p>
I don't know	Responses describe the reason for the robot to do something/ intervene as: I don't know why the robothing did what it did	<p>"I don't know", "dn", "i am actually not sure at this time", "I do not really know why he does what he does"</p>
Other	Responses describe the reason for the robot to do something/ intervene as: not giving a reason, not explaining why, anything, broken sentences, because of a malfunction	<p>"because there was more than one tri", "I think Push-one did what it did because he was tryinf to get reactions from Laura and Jim" "It was confused", "he was broken", "cause it wanted to do what the other kids were doing"</p>

Table 20: The table details the codebook used to analyze the open-question: Why do you think Push-one did what it did?. On the right, the codes used to annotate the corpus of answers. In the center, the definition used for each code. On the right, examples taken from the corpus of answers. Please note that the answers are not corrected, but copied as they are with typos and grammatical errors.

Codebook for Open-Question: What do you think Push-one was doing?		
Code	Definition	Examples
Giving	Responses describe the action of the robothing as: Bringing, pushing to the children, dragging a piece of the puzzle to the children	"he gave the boy the other yellow triangle", "pushing blocks to them" "puzzle and giving" "sharing to help"
Taking	Responses describe the action of the robothing as: Pushing away, tacking away, dragging away, running away or stealing a piece of puzzle/block from one or both of the children	"Push-one took the block from Laura and Jim!!!" "Taking away a block from them" "Runnig away with the triangle" "stealing a blok to stop them"
Making/Playing	Responses describe the action of the robothing as: making a puzzle, doing a puzzle, moving objects around, pushing objects around, pushing pieces of puzzle around, finishing a puzzle	"Push one was making a puzzle like Laura and Jim" "He was pushing blocks" "Push-one wants to match its own puzzles" "It push the puzzle on the paper"
Other	Responses describe the action of the robothing as: cleaning, moving around, detecting objects. Any action not related to the scenario	"Clening up" "movement, trying to find a block to use" "moving" "tidying up its mess"
I don't know	Responses describe the action of the robothing as: an unknown action, something that is not explainable or describable	"i do not know, nothing?" "dont know" "I dont' know"
None	Responses describe the action of the robothing as: a social quality of the robothing, it describes the intention, not the action. Anything that is not an action, but more related to a reason.	"helping" "helping so they didn't fight" "he was distracted by its own puzzle, it did not want to help" "it notices the fight and this time it is nice"

Table 21: The table details the codebook used to analyze the open-question: What do you think Push-one was doing?. On the right, the codes used to annotate the corpus of answers. In the center, the definition used for each code. On the right, examples taken from the corpus of answers. Please note that the answers are not corrected, but copied as they are with typos and grammatical errors.

Measures

We assessed how the children read and explained the intention of the robothing's actions and motion styles (i.e., legibility), whether they attributed social qualities to the robot and whether participants perceived the robot as helpful in the conflict situation. The survey measures were as follows:

1. **Legibility:** We sought to investigate how participants read the robothing's behaviors and explain the robothing's intention behind the behaviors, often considered in HRI as the legibility of a robot's action. To this end, drawing from Dragan's definition of legibility [83], we operationalize legibility as a motion that enables an observer to infer motion goal and intention. To evaluate legibility, we included three open questions. Two open questions were "what" questions about the actions' of the robothing (*What do you think Push-one was doing?*) and of the children (*What do you think Laura and Jim were doing?*). One question asks what the robothing is doing in the scenario, and the second asks what the children are doing. We inserted the latter question about the children's actions as an extra assessment of children's understanding of the scenario. It is crucial to discern whether participants understood that a conflict over possessions of objects is happening. We included a "why" question (*Why do you think Push-one did what it did?*) to explain the reason for the robothing behaviors, i.e., the intention behind the robothing behaviors. Typically, "why" questions are sufficient to discern the intention of a robot [240], because people explain the reason behind an action answering a "why" question. However, children find it quite challenging to answer "why" questions because children are still developing their abilities to understand another's agent mind [2].

Therefore, we included both the “what” and “why” questions because children find it easier to explain “what” questions. [2, 240, 71, 17].

2. **Ascription of social qualities:** In our related work [228, 207], we have found that people infer social qualities from a robot's actions and motion styles. Therefore, we wanted to assess what social qualities participants ascribe to robothing behaviors. As children might have had a hard time responding to an open question related to their ascription of social qualities. Therefore, we drew inspiration from a validated instrument, The Adjective Checklist [331], an instrument developed to assess children's attitudes towards peers. In the Adjective Checklist, children selected words that describe a peer of theirs from a pool of seventy adjectives. In a similar vein, we presented the participants of the study with a pool of adjectives potentially describing the robothing's social qualities. To build our pool of adjectives, we ran a pilot test with adults ($n = 7$; mean age = 23; all English speakers from North America). After showing the pilot test's participants the nine experimental videos, we asked them to name adjectives for each of the videos. We selected the most named adjectives (21), and we eliminated doubles. Then, we asked the pilot test's participants to collaboratively cluster the resulting adjectives in higher-level macro-categories that capture the underlying social qualities of the adjectives. Pilot test participants clustered 21 adjectives in three categories (i.e., prosocial, passive, antisocial social qualities), which they deemed representing the social qualities of each adjective. Table 22 lists the resulting adjectives, specifying with which of videos adjectives were associated the most. From the pool of 21 resulting adjectives, we asked children to select as many adjectives as they wished to describe the robothing's behavior in the video (instructions were as follows: *Pick the adjectives that best describe Push-one. Select all the ones that apply*).
3. **Helpfulness:** The robothing behaviors we examined are all meant to intervene in a conflict. Hence, asking the children about the helpfulness of the robot in the situation enabled us to discern whether children consider the robothing's actions to be a helpful intervention in the conflict. We used the validated helpfulness item from our previous work, [411] (See Chapter 4, Study 2), to assess how helpful children perceived the robothing's actions to be. The 5-point Likert scale item was as follows: *“How helpful was Push-one to Laura and Jim in the situation?”*. The item was anchored from “very unhelpful” to “very helpful”.

7.2.4 Data Analysis

We analyzed the data as follows:

Category	Adjectives in the survey	Associated with conditions
Prosocial social qualities	generous, friendly, helpful collaborative, nice, kind, happy-go	giving, sine-wave giving, linear giving, jerky
Antisocial social qualities	bad, nasty, mean, unfriendly bossy, disruptive, aggressive	taking, sine-wave taking, linear taking, linear
Passive social qualities	dull, indifferent, unobservant, careless, unconcerned distracted, unresponsive	not intervening, sine-wave not intervening, linear not intervening jerky

Table 22: The table lists the adjectives participants could select to describe the social qualities of the robthing behaviors (Ascription of Social Qualities Item). We chose the adjectives used in the survey during a pilot test with adults. Pilot-test's participants clustered the adjectives in three macro-categories of social qualities: prosocial, passive, and antisocial social qualities. Adjectives in the related categories were associated with different conditions, as reported in the third column of the table.

Codebook for Open-Question: What do you think Laura and Jim were doing?		
Code	Definition	Examples
Fighting	Responses describe the actions of the children as: quarrel for a block, having an argument over a block, pulling a block towards each other, fighting	"fighting" "sort and argue" "they got in a fight about one piece" "not sharing" "squabbling over a yellow block"
Making/Playing	Responses describe the actions of the children as: making a puzzle, arranging puzzle pieces on the outline, playing with the puzzle pieces	"kids were completing the puzzle" "trying to build a square with the piece" "finishing the puzzle" "playing the game"
Other	Responses describe the actions of the children as: either a non-specified sequence of action, a mood or feeling or an action that does not fall on the above.	"they always do the same" "mad at push one" "i think they were telling Push-one what to do" "They follow Push-one"
I don't know	Responses describe the actions of the children: an unknown action, something that is not explainable or describable	"dont know" "I dont' know"

Table 23: The table details the codebook used to analyze the open-question: What do you think Laura and Jim were doing?. On the right, the codes used to annotate the corpus of answers. In the center, the definition used for each code. On the right, examples taken from the corpus of answers. Please note that the answers are not corrected, but copied as they are with typos and grammatical errors.

		took away a block	giving a block	taking care of its own puzzle	Total (counts)
Linear	Not Intervening	0	2	28	30
	Giving	2	21	7	30
	Taking	28	0	2	30
	Total	30	23	37	90
Sine-wave	Not Intervening	0	0	30	30
	Giving	1	29	0	30
	Taking	27	0	3	30
	Total	28	29	33	90
Jerky	Not Intervening	5	0	25	30
	Giving	0	28	2	30
	Taking	27	3	0	30
	Total	32	31	27	90
Total	Not Intervening	5	2	83	90
	Giving	3	78	9	90
	Taking	82	3	5	90
	Total	90	83	97	270

Table 24: In the table, the results of the manipulation check for the robothing's action. Numbers in the table are counts, presented per between-subject factors and within-subjects factors. Participants replied to one multiple choice item "What do you think best describes what Push-one did in the video?". Participants' options were: Push-one took away a block, Push-one was giving a block, Push-one was taking care of its own puzzle.

1. **Legibility items:** The open-question items were annotated in categories with an inductive approach from Grounded Theory. The unit of analysis is the sentences answering the open-questions. In total, we coded 810 answers, 270 per between-subject condition. Coding was carried out manually on printed paper during open-coding and axial coding, the 810 answers were printed on paper in Post-It format. During selective coding, annotations were carried out on printed paper. The final annotations of the 810 answers were transcribed in IBM SPSS software for statistical analysis. The coding procedure was as follows: First, two researchers, one blind to the scope of the study and the data collection, carried out 8.5 hours of open-coding of the corpus of answers to assess what categories would emerge from the data. The resulting categories for each of the open-question items are presented in Table 20, Table 21, and Table 23. Then the two researchers used axial coding to cluster in categories that related one to the other. Finally, the researchers carried out sequential coding to apply higher-level categories. Resulting categories for the question "What do you think Push-one was doing" were: giving, taking, making/playing, other, I don't know, prosocial, antisocial, passive. Resulting categories for the question "What do you think Laura and Jim were doing" were: fighting, getting, making/playing other. Resulting categories for the "Why do you think Push-one did what it did?" question were: prosocial, antisocial, not intervening, controlled, positive attribute, negative attribute, other (See Table 20 for the full explanation and examples for each of the cate-

		in waves	jerky	straight	Total (counts)
Not Intervening	Linear	1	4	25	30
	Sine-wave	20	1	9	30
	Jerky	6	14	10	30
	Total	27	19	44	90
Giving	Linear	10	4	16	30
	Sine-wave	23	4	3	30
	Jerky	10	9	11	30
	Total	43	17	30	90
Taking	Linear	0	11	19	30
	Sine-wave	21	4	5	30
	Jerky	2	26	2	30
	Total	23	41	26	90
Total	Linear	11	19	60	90
	Sine-wave	64	9	17	90
	Jerky	18	49	23	90
	Total	93	77	100	270

Table 25: In the table, the results of the manipulation check for the robthing's motion style. Numbers in the table are counts, presented per between-subject factors and within-subjects factors. Participants replied to one multiple choice item "In what way do you think Push-one was moving in the video?". Participants' options were: Push-one took away a block, Push-one was giving a block, Push-one was taking care of its own puzzle.

gories) to the cluster and develop a codebook. We structured a unified codebook following guidelines from [239] with a code, a definition, and examples. The answers were coded iteratively and independently, then we compared the agreement to resolve any mismatches. After every iteration, we updated the codebook accordingly. We carried out six independent iterations on 10% of the corpus before reaching a saturation point. We reached a good to very good agreement. Namely, for the question "What do you think Push-one was doing" $d = 0.828$ $p = .000$, for the question "What do you think Laura and Jim were doing" $d = 0.938$ $p = .000$, and for the "Why do you think Push-one did what it did?", $d = 0.836$ $p = .000$. We analyze the coding results qualitatively by comparing counting and percentages.

2. **Ascription of social qualities items:** We analyzed the distribution of the counts of the adjectives over between (linear, sine-wave and jerky) and within subjects factors (giving, taking, not intervening) with Pearson Chi-Square tests. We use the values of the standardized residuals to interpret the Chi-Square results. Standardized residuals show represent the error between the observed frequency of the counts (i.e., the frequency of the results) and the expected frequency (i.e., what a Chi-square model predicts). A positive value of the standardized residuals indicate that there are more counts than expected and a negative value that there are fewer counts than expected. A standardized

residual value higher than 1.96 or lower than -1.96 for for either more or fewer expected counts is considered significant at $p < 0.05$.

3. **Helpfulness Item** A two-way mixed ANOVAs was conducted to evaluate the effects of action strategy of the robothing actions (giving, taking away, not intervening) and the motion style (neutral, sine-wave, jerky) on the perceived helpfulness of the robot.

Manipulation Check

To discern whether our manipulation of a robothing's action and motion style was successful, we administrated a manipulation check item in the survey. Similarly to our previous work [411] (see Chapter 4, Study 2) we included two multiple-choice items. We asked *What do you think best describes what Push-one did in the video?* and *In what way do you think Push-one was moving in the video?*. For each of the two items, children could select only one answer corresponding to the conflict-resolution actions (1: is giving a block, 2: is taking a block away, 3: is taking care of its puzzle) or motion styles (1: in waves, 2: jerky, 3: straight). We used a simplified language to describe the motion style: from our pilot tests, we gathered that linear and sine-wave were complex words for children. Therefore, we used simpler terms, still capturing the same concept. The manipulation check questions were the last questions asked for each video.

The results of the manipulation check show that the robot's actions were the easiest to recognize (83 children out of 90 recognized the not intervening action, 78 the giving action, and 82 the taking action). The motion styles were more challenging to tease apart (60 of 90 children recognized the linear motion, 64 of 90 the sine-wave motion, 49 of 90 the jerky motion). All in all, we consider the manipulation check successful. With their answers, participants labelled both conflict-resolution actions and motion styles correctly, at rates well above chance (actions $\chi^2(d = 14) = 416.364$, $p < .000$; motion style $\chi^2(d = 4) = 119.7902$, $p < .000$).

7.2.5 *Findings and Results*

In this section, we present the qualitative findings and quantitative results of the survey. We discuss the results per measure. The results answer the main question of the study: *How do children interpret the intention of different robothing's actions to intervene in a conflict?*. We present the results per sub-question of this main question, as follows: **Sub-Question A:** *How does a motion style (linear vs. sine-wave vs. jerky) impact the way children interpret different robothing's actions to intervene in a conflict?*

Sub-Question B: *What are the effects of a robothing motion style (linear vs. sine-wave vs. jerky) and actions (giving vs. taking away vs. non-intervening) on children's perception of helpfulness of the robot?*

Sub-Question C: *What are the effects of a robothing motion style (linear vs. sine-wave vs. jerky) and actions (giving vs. taking away vs. non-intervening) on children's perception of social qualities of the robot?*

Sub-question 1a: How does a motion style impact the way children interpret different robothing's actions to intervene in a conflict?

Here, we report the findings from the annotation of the open-question item *"What do you think Push-one was doing?"* summarized in Table 26. First, we examine the findings from the perspective of the within-subject conditions. Participants described the robothing's action for **giving an object** as bringing, pushing, and sharing an object (coded as "giving", 54% of total responses for the within-subject condition giving). We found few differences in the responses on between-subject conditions (i.e., motion style), but we observe that when the robothing was giving an object with a linear motion style, there was more variability of answers. Only 36,7% of the responses were coded "giving" when the robot was giving an object with a linear motion style, while 56,6% of the responses were coded as "giving" when the robot was giving an object with a sine-wave motion style and 70% of the responses coded as "giving" when the robot was giving an object with a jerky motion style.

Participants described the robothing's action for **taking an object** as pushing away, bringing away, taking away, running away with and stealing an object (coded as "taking", 60% of total responses for the within-subject condition taking). We found few differences in the responses of the between-subject conditions (i.e., motion style): 63% of the responses were coded "taking" when the robothing was taking away an object with a linear motion style, 50% of the responses were coded "taking" when the robothing was taking away an object with a sine-wave motion style, and 66,7% were coded "taking" when the robothing was taking away an object with a jerky motion style.

Similarly, participants described the robothing's action for **not intervening** as doing a puzzle, playing with a puzzle, and doing things with a puzzle (coded as "making/playing", 56,7% of total responses for the within-subject condition not intervening). We found few differences in the responses on the between-subject conditions (i.e., motion style). 53,3% of the responses were coded "making/playing" when the robothing was not intervening with a linear motion style, 60% of the responses were coded "making/playing" when the robothing was not intervening with a sine-wave motion style, 53,7% of the responses were coded "making/playing" when the robothing was not intervening with a jerky motion style.

Interestingly, we observed that a relevant number of answers were coded as "none" that is not describing an action. As they represent a substantial number of the coding (23,7 %), we inspected the participants' answers. We

noticed that the “none” answers describe the intention of the robothing, rather than the action. We address these findings in the Discussion section.

We also report the findings from the annotation of the open-question item *“What do you think Laura and Jim were doing?”*. Overall, the participants understood that the children were experiencing a conflict. We found that in 70% of their answers over all of the factors, participants described the actions of the children as fighting, as having a dispute, or as a conflict (coded as “fighting”). 20,7% of the answers describe the actions as making or playing in the game (coded as “making/playing”, 8,1% gave different answers (coded “other”), only 1,1% did not know what the children were doing in the video stimuli.

We report the findings from the annotation of the open-question item *“Why do you think Push-one did what it did?”* summarized in Table 27. Looking at the within-subject factors (i.e., actions to intervene in conflict), participants explained the robothing’s intention for **giving an object** as wanting to do something to help children in the situation and to stop the fight happening between the two children (code prosocial, 62% of the total responses). We find few differences in the responses on between-subject conditions (i.e., motion style), but we observe that when the robothing was giving an object with a linear motion style, there was more variability of answers. Only 36% of the responses were coded “prosocial” when the robot was giving an object with a linear motion style, while 70% of the responses were coded as “prosocial” when the robot was giving an object with a sine-wave motion style and 80% of the responses coded as “prosocial” when the robot was giving an object with a jerky motion style.

The most surprising finding is related to the **taking action** and the **sine-wave** motion style. Participants found the intention of the robot to be mostly prosocial. 43% of the responses were coded “prosocial” when the robothing was taking an object with a linear motion style, 50% of the responses were coded “prosocial” when the robothing was taking an object with a sine-wave motion style, 40% of the responses were coded “prosocial” when the robothing was taking an object with a jerky motion style. When the robothing was taking away an object, the robothing’s intention was often considered “antisocial” with a linear (16,7%) and especially with a jerky (36,7% motion style). Interestingly, when the robothing was taking an object with a sine-wave motion style, the robot was not considered having an antisocial intention (no answer coded as “antisocial”).

Participants explained the robothing intention for **not intervening** as the robothing minding its own business, keeping on playing with its puzzle blocks undisturbed, or wanting to finish its puzzle (coded not intervening) (30% of the total responses). We do not find many differences in the responses on between-subject conditions (i.e., motion style), but we observe that the not intervening action irrespective of the style has many instances in which participants did not know what to answer (25% of the total) and

that in few cases the not intervening action was considered as having an antisocial intention (10% of the total).

For the question “Why do you think Push-one did what it did?” we found more instances of answers stating that participants did not know why the robothing does what it does than for the question “What do you think Push-one was doing?”. In all the within-subject factors (i.e., actions of the robothing) and between-subject conditions (i.e., motion style), we found some instances in which participants respond that others controlled the robothing (in total 9,6% of all the answers). Participants answered that they did not know why the robothing acted as it did, mainly when the robot was not intervening (25,6%). Participants considered the robothing to be controlled only 10% of the time when it was giving an object and 15,6% of the times when the robot was taking away an object. Looking at the between-subjects (i.e., motion style) findings, we do not observe any differences in the “I don’t know answers” per condition.

Sub-question 1b: What are the effects of a robothing’s motion style and actions on children’s perception of helpfulness of the robothing?

We found a **statistically significant interaction effect** on the perceived helpfulness of the action of the robothing and the motion style, $F(4, 174) = 9.767$, $p < .001$, partial $\eta^2 = .183$ (see Figure 66). To understand where the interaction effect lies, we carried out the simple main effects and pairwise comparisons for both robothing’s actions and motion styles.

First, we analyzed the **simple main effects of robothing motion style**. Interestingly, we found statistically significant differences in helpfulness between motion styles of the robothing and all the three actions: The giving action of the robot, $F(2, 87) = 12.129$, $p < .001$, partial $\eta^2 = .218$, between motion styles, and the not intervening action of the robot, $F(4, 87) = 5.162$, $p = .008$, partial $\eta^2 = .106$ between motion styles and, the taking action of the robot, $F(2, 87) = 11.937$, $p < .001$, partial $\eta^2 = .215$.

Giving an object with both a **sine-wave** and a **jerky** motion style positively impact children’s perception of helpfulness, with not statistical difference between the two motion styles ($M = -0.10$, $SE = 0.270$, $p = .927$). The giving action of the robothing was perceived as similarly helpful both in the sine-wave and the jerky motion style (see Figure 66). On the other hand, when the robothing was giving an object with a linear style, the perception of helpfulness was significantly lower compared to both the sine-wave ($M = -1.10$, $SE = 0.270$, $p < .001$) and the jerky motion style ($M = -1.20$, $SE = 0.270$, $p < .001$).

When the robothing was **not intervening**, the perception of its helpfulness was significantly greater in the **jerky motion style** compared to both the sine-wave ($M = 0.63$, $SE = 0.255$, $p = .039$) and the linear motion style ($M = 0.77$, $SE = 0.255$, $p = .010$). No differences were found between the sine-wave and linear style, $M = 0.13$, $SE = 0.255$, $p = .860$.

Figure 66: The figure depicts the interaction effect between the action of the robot (giving or not intervening or taking) and the style of the action (linear, sine-wave, jerky) on the perceived helpfulness of the robot.

Interestingly, the **sine-wave motion style** positively impacts children's perception of helpfulness of the robothing also when the robothing was **taking an object**. We found that the perception of helpfulness was significantly greater in the sine-wave motion style compared to both the jerky ($M = 1.67$, $SE = 0.343$, $p < .001$) and the linear motion style ($M = 0.97$, $SE = 0.343$, $p = .016$) of the robothing. No differences were found between the linear and jerky style. $M = -0.70$, $SE = 0.343$, $p = .108$.

Secondly, we analyzed the **simple main effects** of the **robothing actions** (See Figure 67). We found simple main effects on the perception of helpfulness for all the three actions that the robothing exhibited and the linear motion style of the robothing, $F(2, 58) = 11.995$, $p < .000$, partial $\eta^2 = .293$. As expected, when the robothing was giving an object, participants perceived the robot as being more helpful than when the robot was not intervening ($M = 1.90$, $SE = 0.366$, $p < .001$). Surprisingly, the taking action of the robothing ($M = 1.07$, $SE = 0.332$, $p = .010$) was perceived significantly more helpful compared to the not intervening action. No differences were found between the giving and taking actions on the perception of helpfulness ($M = -0.83$, $SE = 0.458$, $p = .237$).

We also found a statistically significant difference in the perception of helpfulness between actions of the robot at the sine-wave style of the robot ($F(2, 58) = 56.323$, $p < .001$, partial $\eta^2 = .660$). Again, children perceived the robothing behavior as more helpful both when the robothing was giving an object ($M = 2.87$, $SE = 0.224$, $p < .001$) and when the robot was taking away an object ($M = 1.90$, $SE = 0.330$, $p < .001$) compared to the not intervening action. Participants perceived the robothing significantly more helpful when giving an object than when taking an object ($M = -0.97$, $SE = 0.260$, $p = .003$).

Figure 67: The figure depicts the interaction effect between the style of the action and the actions of the robothing on the perceived helpfulness of the robot.

Similarly, we found a significant difference in the perception of helpfulness between actions of the robothing at the jerky motion style of the robothing, $F(2, 58) = 85.063$, $p < .001$, partial $\eta^2 = .746$. When the robothing was a giving a block, the robothing was considered significantly more helpful than when it was taking away an object ($M = 2.73$, $SE = 0.219$, $p < .001$) or not intervening ($M = 2.33$, $SE = 0.205$, $p < .001$). We found no difference between the taking and not intervening actions ($M = -0.40$, $SE = 0.252$, $p = .369$).

Sub-question 1c: What are the effects of a robothing's motion styles and actions on children's ascription of social qualities to the robothing?

A chi-square test for association on the robothing actions (within-subject factors) and the robothing motion styles (between-subject factors) had an effect on the adjective counts. We report the adjective per categories (See Table 22): prosocial, antisocial and passive. To explain where the significance lay we report standardized residuals values (i.e., z values) Table 28 summarize the results and highlights significant results.

- **Antisocial Adjectives.** There was a statistically significant association ($\chi^2 = 25.835$, $d = 2$, $p < .000$, $\phi = .309$, $p < .000$). between the adjective **bad** and the robothing actions (within-subject factors). There are significantly fewer counts in the giving ($z = -2$) within-subjects condition than in the taking ($z = 4$) and not intervening within-subjects condition ($z = -1.8$).

There was a statistically significant association between the adjective **nasty** and both the robothing actions (within-subject factors, $\chi^2 = 20.495$, $d = 2$, $p < .000$, $\phi = 0.276$, $p < .000$) and robothing motion styles (between-subjects factors, $\chi^2 = 6.907$, $d = 2$, $p = .032$,

$\phi = .160, p = .032$). To understand where the association lies, we inspect the standardized residuals. There are significantly more counts than expected in the **taking** ($z=3.4$) within-subject condition and fewer counts than expected in the giving within-subject condition ($z= -2.5$).

There was a statistically significant association ($\chi^2 = 11.859, d = 2, p = .0003, \phi = .210, p = .003$) between the adjective **mean** and the robothing actions (within-subject factors). To understand where the association lies, we inspect the standardized residuals. There are more counts than expected in the **taking** ($z= 2.7$) within-subject condition and fewer counts than expected in the giving ($z= -1.8$) within-subject condition and the not intervening within-subject condition ($z= -0.8$).

There was a statistically significant association between the adjective **unfriendly** and both the robothing actions (within-subject factors, $\chi^2 = 27.595, d = 2, p < .000, \phi = .320, p < .000$) and robothing motion styles (between-subjects factors, $\chi^2 = 19.131, d = 2, p < .000, \phi = .266, p < .000$). There are significantly fewer counts in the giving within-subjects condition ($z= -2.5$) and significantly more counts in the **taking** within-subjects condition ($z= 4$). Moreover, there are significantly more counts in the **linear** ($z= 4$) between-subject condition than the other between-subjects conditions.

There was a statistically significant association between the adjective **disruptive** and both the robothing actions (within-subject factors, $\chi^2 = 19.712, d = 2, p < .000, \phi = .270, p < .000$) and robothing motion styles (between-subjects factors, $\chi^2 = 7.659, d = 2, p = .022, \phi = .168, p = .022$). There are significantly fewer counts in the giving within-subjects condition and significantly more counts in the **taking** within-subjects condition. There are significantly fewer counts in the sine-wave between-subject condition than the other between-subjects conditions.

There was a statistically significant association between the adjective **aggressive** and both the robothing actions (within-subject factors, $\chi^2 = 17.604, d = 2, p < .000, \phi = .255, p < .000$) and robothing motion styles (between-subjects factors, $\chi^2 = 12.096, d = 2, p = .002, \phi = .212, p = .002$). There are significantly fewer counts in the giving within-subjects condition ($z= -2$) and significantly more counts in the **taking** within-subjects condition ($z= 3.2$). There are significantly fewer counts in the sine-wave between-subject condition ($z= -2$) and more counts in the **jerky** between-subject condition ($z= 1.8$).

There was a statistically significant association between the adjective **bossy** and both the robothing actions (within-subject factors, $\chi^2 = 20.495, d = 2, p < .000, \phi = .276, p < .000$) and robothing motion styles (between-subjects factors, $\chi^2 = 12.682, d = 2, p = .002, \phi = .217, p = .002$). There are significantly fewer counts in the giving

within-subjects condition ($z = -2.5$) and significantly more counts in the **taking** within-subjects condition ($z = 3.4$). There are significantly fewer counts in the sine-wave between-subject condition ($z = -2.1$) and significantly more counts in the **jerky** between-subject condition ($z = 2.6$).

- **Prosocial Adjectives.** There was a statistically significant association ($\chi^2 = 55.996, d = 2p = < .000$, association $\phi = 0.455, p = < .000$) between the adjective **generous** and the robothing actions (within-subject factors). There are significantly more counts ($z = 5.6$) in the **giving** within-subject condition than in the taking ($z = -2.7$) and not intervening within-subject condition ($z = -2.9$).

There was a statistically significant association between the adjective **friendly** and both the robothing actions (within-subject factors, $\chi^2 = 42.481, d = 2p = < .000$, $\phi = .397, p = < .000$) and robothing motion styles (between-subjects factors, $\chi^2 = 10.871, d = 2p = .004$, $\phi = .201, p = < .032$). There are significantly more counts ($z = 4.5$) in the **giving** within-subject condition than in the taking ($z = -1.7$) and not intervening within-subject condition ($z = -2.8$). Moreover, there are significantly more counts ($z = 2.3$) in the **sine-wave** between-subject factor than in the linear ($z = -1.3$) and jerky between-subject condition ($z = -0.9$).

There was a statistically significant association between the adjective **helpful** and both the robothing actions (within-subject factors, $\chi^2 = 61.960, d = 2p = < .000$, $\phi = 0.479, p = < .000$) and robothing motion styles (between-subjects factors, $\chi^2 = 17.44, d = 2p = .000$, $\phi = .254, p = < .000$). There are significantly more counts ($z = 4.4$) in the **giving** within-subject condition than in the not intervening within-subject factor ($z = -4.6$). Moreover, there are significantly more counts ($z = 2.8$) in the **sine-wave** between-subject condition than in the linear ($z = -1.4$) and jerky between-subject condition ($z = -1.4$).

There was a statistically significant association ($\chi^2 = 11.726, d = 2p = .003$, $\phi = .208, p = < .003$) between the adjective **collaborative** and the robothing actions (within-subject factors). There are significantly more counts ($z = 2$) in the **giving** within-subject condition than in the taking ($z = 0.6$) and not intervening within-subject condition ($z = -2.5$).

There was a statistically significant association ($\chi^2 = 23.046, d = 2p = < .000$, $\phi = .292, p = < .000$) between the adjective **nice** and the robothing actions (within-subject factors). There are more counts ($z = 3.2$) in the **giving** within-subject factor than in the taking ($z = -1.1$) and not intervening within-subject condition ($z = -2.1$).

There was a statistically significant association between the adjective **happy-go-lucky** and both the robothing actions (within-subject factors, $\chi^2 = 20.514, d = 2p = < .000$, $\phi = .276, p = < .000$) and robothing

motion styles (between-subjects factors, $\chi^2 = 25.621, d = 2p = .000, \phi = .308, p = < .000$). There are significantly more counts ($z=3.5$) in the **giving** within-subject condition than in the taking ($z= -1.6$) and not intervening within-subject condition ($z= -1.8$). Moreover, there are significantly more counts ($z=3.8$) in the **sine-wave** between-subject condition than in the linear ($z= -1.2$) and jerky between-subject condition ($z= -2.6$).

There was a statistically significant association between the adjective **kind** and both the robothing actions (within-subject factors, $\chi^2 = 31.001, d = 2p = < .000, \phi = .339, p = < .000$) and robothing motion styles (between-subjects factors, $\chi^2 = 15.726, d = 2p = .000, \phi = .241, p = < .000$). There are significantly more counts ($z=4$) in the **giving** within-subject condition than in the taking ($z= -1.5$) and not intervening within-subject condition ($z= -2.5$). Moreover, there are significantly more counts ($z=2.9$) in the **sine-wave** between-subject condition than in the linear ($z= -1.1$) and jerky between-subject condition ($z= -1.8$).

- **Passive Adjectives.** There was a statistically significant association between the adjective **dull** and both the robothing actions (within-subject factors, $\chi^2 = 7.746, d = 2p = .021, \phi = 0.169, p = .021$) and robothing motion styles (between-subjects factors, $\chi^2 = 17.705, d = 2p = < .000, \phi = .256, p = < .000$). The standardize residuals results do not provide an indication about where the association lies.

There was a statistically significant association ($\chi^2 = 7.236, d = 2p = .027, \phi = .164, p = .027$) between the adjective **indifferent** and the robothing motion styles (between-subjects factors). There are significantly more counts ($z=2.9$) in the **linear** between-subject condition than in the sine-wave ($z= -1.4$) and jerky between-subject condition ($z= -0.6$).

There was a statistically significant association ($\chi^2 = 32.456, d = 2p = < .000, \text{association } \phi = .347, p = < .000$) between the adjective **unobservant** and the robothing actions (within-subject factors). There are significantly more counts ($z=4.3$) in the **not intervening** within-subject condition than in the taking ($z= -2$) and giving within-subject condition ($z= -2.3$).

There was a statistically significant association ($\chi^2 = 46.735, d = 2p = < .000, \text{association } \phi = .416, p = < .000$) between the adjective **distracted** and the robothing actions (within subject factors). There are significantly more counts ($z=5.2$) in the **not intervening** within-subject condition than in the taking ($z= -2.3$) and giving within-subject condition ($z= -3$).

There was a statistically significant association ($\chi^2 = 26.974, d = 2p = < .000, \text{association } \phi = .316, p = < .000$) between the adjective

unconcerned and the robothing actions (within-subject factors). There are significantly more counts ($z=3.9$) in the **not intervening** within-subject condition than in the taking ($z= -1.5$) and giving within-subject condition ($z= -2.3$).

There was a statistically significant association ($\chi^2 = 24,970$, $d = 2p = < .000$, association $\phi = .304$, $p = < .000$) between the adjective **unresponsive** and the robothing actions (within-subject factors). There are significantly more counts ($z=3.9$) in the **not intervening** within-subject condition than in the taking ($z= -2.1$) and giving within-subject condition ($z= -1.8$).

There was a statistically significant association between the adjective **careless** and both the robothing actions (within-subject factors, $\chi^2 = 11.784$, $d = 2p = .003$, $\phi = 0.208$, $p = .003$) and robothing motion styles (between-subjects factors, $\chi^2 = 10.481$, $d = 2p = .005$, $\phi = .197$, $p = < .005$). There are significantly more counts ($z=2.2$) in the **not intervening** within-subject condition than in the taking ($z= -2.3$) and giving within-subject condition ($z= -1.8$). Moreover, there are significantly more counts ($z=2.2$) in the **linear** between-subject condition than in the sine-wave ($z= -0.2$) and jerky between-subject condition ($z= -2$).

7.2 STUDY 5: HOW CHILDREN UNDERSTAND AND PERCEIVE A ROBOTHING'S
BEHAVIOR TO INTERVENE IN CONFLICTS

What do you think Push-one was doing?		Within-subjects factor: actions			Total
Between-subjects factor: motion style	Code	Not Intervening	Giving	Taking	
Linear	Giving	1	11	0	12
	%	3,3%	36,7%	0,0%	13,3%
	Taking	0	1	19	20
	%	0,0%	3,3%	63,3%	22,2%
	Making/Playing	16	7	3	26
	%	53,3%	23,3%	10,0%	28,9%
	Other	7	5	0	12
	%	23,3%	16,7%	0,0%	13,3%
	I dont know	0	0	1	1
	%	0,0%	0,0%	3,3%	1,1%
	None	6	6	7	19
	%	20,0%	20,0%	23,3%	21,1%
Sine-wave	Total	30	30	30	90
	%	100,0%	100,0%	100,0%	100,0%
	Giving	0	17	0	17
	%	0,0%	56,7%	0,0%	18,9%
	Taking	0	0	15	15
	%	0,0%	0,0%	50,0%	16,7%
	Making/Playing	18	2	7	27
	%	60,0%	6,7%	23,3%	30,0%
	Other	5	0	0	5
	%	16,7%	0,0%	0,0%	5,6%
	None	7	11	8	26
	%	23,3%	36,7%	26,7%	28,9%
Jerky	Total	30	30	30	90
	%	100,0%	100,0%	100,0%	100,0%
	Giving	1	21	1	23
	%	3,3%	70,0%	3,3%	25,6%
	Taking	0	0	20	20
	%	0,0%	0,0%	66,7%	22,2%
	Making/Playing	17	0	0	17
	%	56,7%	0,0%	0,0%	18,9%
	Other	8	0	2	10
	%	26,7%	0,0%	6,7%	11,1%
	I dont know	1	0	0	1
	%	3,3%	0,0%	0,0%	1,1%
All three conditions	None	3	9	7	19
	%	10,0%	30,0%	23,3%	21,1%
	Total	30	30	30	90
	%	100,0%	100,0%	100,0%	100,0%
	Giving	2	49	1	52
	%	2,2%	54,4%	1,1%	19,3%
	Taking	0	1	54	55
	%	0,0%	1,1%	60,0%	20,4%
	Making/Playing	51	9	10	70
	%	56,7%	10,0%	11,1%	25,9%
	Other	20	5	2	27
	%	22,2%	5,6%	2,2%	10,0%
	I dont know	1	0	1	2
	%	1,1%	0,0%	1,1%	0,7%
	None	16	26	22	64
	%	17,8%	28,9%	24,4%	23,7%
	Total	90	90	90	270
	%	100,0%	100,0%	100,0%	100,0%

Table 26: The table reports the coding findings of the question “What do you think Push-one was doing”, to discern the legibility in terms of actions the robthing behaviors. We report counts and percentage per within and between-subject factors.

“Why do you think Push-one did what it did?”		Within-subjects factor: actions			Total
Between-subjects factor: motion style	Code	Not Intervening	Giving	Taking	
Linear	Pro social	0	11	13	24
	%	0,0%	36,7%	43,3%	26,7%
	Anti social	3	0	5	8
	%	10,0%	0,0%	16,7%	8,9%
	Not intervening	9	3	3	15
	%	30,0%	10,0%	10,0%	16,7%
	Controlled	3	6	4	13
	%	10,0%	20,0%	13,3%	14,4%
	Other	7	5	0	12
	%	23,3%	16,7%	0,0%	13,3%
	I dont know	8	5	5	18
	%	26,7%	16,7%	16,7%	20,0%
Total		30	30	30	90
%		100,0%	100,0%	100,0%	100,0%
Sine-wave	Pro social	1	21	15	37
	%	3,3%	70,0%	50,0%	41,1%
	Anti social	6	0	0	6
	%	20,0%	0,0%	0,0%	6,7%
	Not intervening	8	0	1	9
	%	26,7%	0,0%	3,3%	10,0%
	Controlled	3	3	5	11
	%	10,0%	10,0%	16,7%	12,2%
	Positive Attribute	0	1	1	2
	%	0,0%	3,3%	3,3%	2,2%
	Negative Attribute	1	0	1	2
	%	3,3%	0,0%	3,3%	2,2%
	Other	4	2	1	7
	%	13,3%	6,7%	3,3%	7,8%
	I dont know	7	3	6	16
	%	23,3%	10,0%	20,0%	17,8%
Total		30	30	30	90
%		100,0%	100,0%	100,0%	100,0%
Jerky	Pro social	2	24	12	38
	%	6,7%	80,0%	40,0%	42,2%
	Anti social	0	1	11	12
	%	0,0%	3,3%	36,7%	13,3%
	Not intervening	10	0	0	10
	%	33,3%	0,0%	0,0%	11,1%
	Controlled	1	0	1	2
	%	3,3%	0,0%	3,3%	2,2%
	Positive Attribute	0	2	0	2
	%	0,0%	6,7%	0,0%	2,2%
	Negative Attribute	0	0	2	2
	%	0,0%	0,0%	6,7%	2,2%
	Other	9	2	1	12
	%	30,0%	6,7%	3,3%	13,3%
	I dont know	8	1	3	12
	%	26,7%	3,3%	10,0%	13,3%
Total		30	30	30	90
%		100,0%	100,0%	100,0%	100,0%
Total	Pro social	3	56	40	99
	%	3,3%	62,2%	44,4%	36,7%
	Anti social	9	1	16	26
	%	10,0%	1,1%	17,8%	9,6%
	Not intervening	27	3	4	34
	%	30,0%	3,3%	4,4%	12,6%
	Controlled	7	9	10	26
	%	7,8%	10,0%	11,1%	9,6%
	Positive Attribute	0	3	1	4
	%	0,0%	3,3%	1,1%	1,5%
	Negative Attribute	1	0	3	4
	%	1,1%	0,0%	3,3%	1,5%
	Other	20	9	2	31
	%	22,2%	10,0%	2,2%	11,5%
	I dont know	23	9	14	46
	%	25,6%	10,0%	15,6%	17,0%
Total		90	90	90	270
%		100,0%	100,0%	100,0%	100,0%

Table 27: The table reports the coding findings of the question “Why do you think Push-one did what it did?”, to discern the legibility (intention) behind the robthing behaviors. We report counts and percentage per within and between-subject factors.

7.2 STUDY 5: HOW CHILDREN UNDERSTAND AND PERCEIVE A ROBOT/HING'S
BEHAVIOR TO INTERVENE IN CONFLICTS

Bad	Collaborative				Distraction				Unconcerned				Happy-go-lucky				Unresponsive				Bossy				Careless				Kind												
	Linear	Sine-wave	Jerky	Total	Exp. C.	std. res	Not Intervening	Giving	Taking	Total	Exp. C.	std. res	Not Intervening	Giving	Taking	Total	Exp. C.	std. res	Not Intervening	Giving	Taking	Total	Exp. C.	std. res	Not Intervening	Giving	Taking	Total	Exp. C.	std. res											
Not Intervening	1	0	0	1	5	-1.8	Not Intervening	5	3	14	8.3	-2.5	Not Intervening	2	1	0	3	5	-0.9	Not Intervening	8	11	9	28	13.7	3.9	Not Intervening	10	7	2	19	8	3.9	Not Intervening	10	10	3	23	14.7	2.2	
Giving	0	0	0	0	5	-2.2	Giving	2	6	14	8.3	2	Giving	0	1	0	1	5	-1.8	Giving	5	0	0	5	13.7	-2.3	Giving	0	0	0	0	6	-1.8	Giving	5	1	0	6	14.7	-2.3	
Taking	5	2	7	14	5	4	Taking	2	6	10	8.3	0.6	Taking	5	0	6	11	5	2.7	Taking	8	3	8	25	12.7	-2.2	Taking	4	1	10	15	6.3	3.4	Taking	8	3	4	15	14.7	0.1	
Total	6	2	7	15			Total	8	9	8	8.3		Total	7	2	6	15			Total	17	13	11	41	12.7		Total	5	1	13	19			Total	23	14	7	44			
Exp. Count	5	5	5				Exp. Count	8.3	8.3	8.3			Exp. Count	8.3	8.3	8.3				Exp. Count	12.7	12.7	12.7				Exp. Count	6.3	6.3	6.3				Exp. Count	14.7	14.7	14.7				
std. res	0.4	-1.3	0.9				std. res	-0.1	0.2	-0.1			std. res	-0.1	0.2	-0.1				std. res	1.2	0.1	-1.3				std. res	-0.5	-2.1	2.6				std. res	2.2	-0.2	-2				
Generous	Mean																																								
	Linear	Sine-wave	Jerky	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res					
Not Intervening	1	1	1	3	14	-2.9	Not Intervening	2	1	0	3	-0.9	Not Intervening	2	1	0	3	5	-0.9	Not Intervening	8	11	9	28	13.7	3.9	Not Intervening	10	7	2	19	8	3.9	Not Intervening	10	10	3	23	14.7	2.2	
Giving	8	14	13	35	14	5.6	Giving	0	1	0	1	5	-1.8	Giving	0	1	0	1	5	-1.8	Giving	5	0	0	5	13.7	-2.3	Giving	0	0	0	0	6	-1.8	Giving	5	0	0	6	14.7	-2.3
Taking	0	4	0	4	14	-2.7	Taking	5	0	6	11	5	2.7	Taking	5	0	6	11	5	2.7	Taking	8	3	8	25	12.7	-2.2	Taking	4	1	10	15	6.3	3.4	Taking	8	3	4	15	14.7	0.1
Total	9	19	14	42			Total	7	2	6	15			Total	7	2	6	15			Total	17	13	11	41	12.7		Total	5	1	13	19			Total	23	14	7	44		
Exp. Count	14	14	14				Exp. Count	5	5	5				Exp. Count	5	5	5				Exp. Count	12.7	12.7	12.7				Exp. Count	6.3	6.3	6.3				Exp. Count	14.7	14.7	14.7			
std. res	-1.3	1.3	0				std. res	0.9	-1.3	0.4				std. res	0.9	-1.3	0.4				std. res	-0.1	0.2	-0.1				std. res	-0.5	-2.1	2.6				std. res	2.2	-0.2	-2			
Dull																																									
	Linear	Sine-wave	Jerky	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res					
Not Intervening	8	9	1	18	8.7	3.2	Not Intervening	5	4	15	14	-2.1	Not Intervening	2	1	0	3	5	-0.9	Not Intervening	8	11	9	28	13.7	3.9	Not Intervening	10	7	2	19	8	3.9	Not Intervening	10	10	3	23	14.7	2.2	
Giving	2	0	0	2	8.7	-2.3	Giving	12	15	14	41	3.3	Giving	0	1	0	1	5	-1.8	Giving	5	0	0	5	13.7	-2.3	Giving	0	0	0	0	6	-1.8	Giving	5	1	0	6	14.7	-2.3	
Taking	4	0	2	6	8.7	-0.9	Taking	2	14	3	19	-1.1	Taking	5	0	6	11	5	2.7	Taking	8	3	8	25	12.7	-2.2	Taking	4	1	10	15	6.3	3.4	Taking	8	3	4	15	14.7	0.1	
Total	14	9	3	26			Total	19	33	22	74		Total	7	2	6	15			Total	17	13	11	41	12.7		Total	5	1	13	19			Total	23	14	7	44			
Exp. Count	8.7	8.7	8.7				Exp. Count	24.7	24.7	24.7			Exp. Count	24.7	24.7	24.7				Exp. Count	12.7	12.7	12.7				Exp. Count	6.3	6.3	6.3				Exp. Count	14.7	14.7	14.7				
std. res	1.8	0.1	-1.9				std. res	-1.1	1.7	-0.5			std. res	-1.1	1.7	-0.5				std. res	-0.1	0.2	-0.1				std. res	-0.5	-2.1	2.6				std. res	2.2	-0.2	-2				
Indifferent																																									
	Linear	Sine-wave	Jerky	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res					
Not Intervening	7	3	1	11	6.7	1.7	Not Intervening	6	15	8	29	4.3	Not Intervening	2	2	0	4	8.3	-1.5	Not Intervening	8	11	9	28	13.7	3.9	Not Intervening	10	7	2	19	8	3.9	Not Intervening	10	10	3	23	14.7	2.2	
Giving	3	0	0	3	6.7	-1.4	Giving	5	0	0	5	-1.3	Giving	0	1	0	1	5	-1.8	Giving	5	0	0	5	13.7	-2.3	Giving	0	0	0	0	6	-1.8	Giving	5	1	0	6	14.7	-2.3	
Taking	2	0	4	6	6.7	-0.3	Taking	1	2	3	6	-2	Taking	5	0	6	11	5	2.7	Taking	8	3	8	25	12.7	-2.2	Taking	4	1	10	15	6.3	3.4	Taking	8	3	4	15	14.7	0.1	
Total	12	3	5	20			Total	12	17	11	40		Total	7	2	6	15			Total	17	13	11	41	12.7		Total	5	1	13	19			Total	23	14	7	44			
Exp. Count	6.7	6.7	6.7				Exp. Count	13.3	13.3	13.3			Exp. Count	13.3	13.3	13.3				Exp. Count	12.7	12.7	12.7				Exp. Count	6.3	6.3	6.3				Exp. Count	14.7	14.7	14.7				
std. res	2.1	-1.4	-0.6				std. res	-0.4	1	-0.6			std. res	-0.4	1	-0.6				std. res	-0.1	0.2	-0.1				std. res	-0.5	-2.1	2.6				std. res	2.2	-0.2	-2				
Nasty																																									
	Linear	Sine-wave	Jerky	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td> <td>std. res</td>	Giving	Taking	Total	Exp. C.	std. res					
Not Intervening	3	1	0	4	6.3	-0.9	Not Intervening	2	2	0	4	-1.5	Not Intervening	2	2	0	4	8.3	-1.5	Not Intervening	8	11	9	28	13.7	3.9	Not Intervening	10	7	2	19	8	3.9	Not Intervening	10	10	3	23	14.7	2.2	
Giving	0	0	0	0	6.3	-2.5	Giving	1	0	0	1	-1.5	Giving	0	1	0	1	5	-1.8	Giving	5	0	0	5	13.7	-2.3	Giving	0	0	0	0	6	-1.8	Giving	5	1	0	6	14.7	-2.3	
Taking	8	1	6	15	6.3	3.4	Taking	15	0	5	20	4	Taking	5	0	6	11	5	2.7	Taking	8	3	8	25	12.7	-2.2	Taking	4	1	10	15	6.3	3.4	Taking	8	3	4	15	14.7	0.1	
Total	11	2	6	19			Total	18	2	5	25		Total	7	2	6	15			Total	17	13	11	41	12.7		Total	5	1	13	19			Total	23	14	7	44			
Exp. Count	6.3	6.3	6.3				Exp. Count	8.3	8.3	8.3			Exp. Count	8.3	8.3	8.3				Exp. Count	12.7	12.7	12.7				Exp. Count	6.3	6.3	6.3				Exp. Count	14.7	14.7	14.7				
std. res	1.9	-1.7	-0.1				std. res	3.3	-2.2	-1.2			std. res	3.3	-2.2	-1.2				std. res	-0.1	0.2	-0.1				std. res	-0.5	-2.1	2.6				std. res	2.2	-0.2	-2				
Friendly																																									
	Linear	Sine-wave	Jerky	Total	Exp. C.	std. res	Not Intervening <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.</td>	Giving	Taking	Total	Exp. C.	std. res <th>Not Intervening</th>	Not Intervening	Giving	Taking	Total	Exp. C. <td>std. res<th>Not Intervening</th></td> <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.<td>std. res<th>Not Intervening</th></td><td>Giving</td><td>Taking</td><td>Total</td><td>Exp. C.<td>std. res<th>Not Intervening</th></td><td>Giving</td><td>Taking</td><td>Total</td><td>Exp. C.<td>std. res</td></td></td></td>	std. res <th>Not Intervening</th>	Not Intervening	Giving	Taking	Total	Exp. C. <td>std. res<th>Not Intervening</th></td> <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.<td>std. res<th>Not Intervening</th></td><td>Giving</td><td>Taking</td><td>Total</td><td>Exp. C.<td>std. res</td></td></td>	std. res <th>Not Intervening</th>	Not Intervening	Giving	Taking	Total	Exp. C. <td>std. res<th>Not Intervening</th></td> <td>Giving</td> <td>Taking</td> <td>Total</td> <td>Exp. C.<td>std. res</td></td>	std. res <th>Not Intervening</th>	Not Intervening	Giving	Taking	Total	Exp. C. <td>std. res</td>	std. res					
Not Intervening	2	4	5	11	24.7	-2.8	Not Intervening	0	1	0	1	-1.5	Not Intervening	2	1	0	3	5	-0.9	Not Intervening	8	11	9	28	13.7	3.9	Not Intervening	10	7	2	19	8	3.9	Not Intervening	10	10	3	23	14.7	2.2	
Giving	14	19	14	47	24.7	4.5	Giving	1	0	0	1	-1.5	Giving	0	1	0	1	5	-1.8	Giving	5	0	0	5	13.7	-2.3	Giving	0	0	0	0	6	-1.8	Giving	5	1	0	6	14.7	-2.3	
Taking	2	13	1	16	24.7	-1.7	Taking	5	0																																

7.2.6 Discussion

We discuss the findings and results of Study 5 per sub-research question, followed by the main research question. Then, we address design implications and methodological implications for HRI. Finally, we reflect on the limitations of Study 5.

Sub-question 1a: How Does a Motion Style Impact the Way Children Interpret Different Robothing's Actions to Intervene in a Conflict?

The robothing's motion styles appear to have no particular impact on the way children interpret its action to intervene in a conflict. There is an indication that the sine-wave motion style somehow reinforces the prosocial intention of the taking action, as shown by the coding findings. While the HRI literature has gathered mixed results about sine-wave locomotion [207], and our co-design workshops yielded similar insights. However, we cannot draw definitive conclusions from our legibility findings.

Sub-question 1b: What Are the Effects of a Robothing's Motion Style and Actions on Children's Perception of Helpfulness of the Robothing?

We found that actions have the most effects on children's perception of helpfulness. The giving behavior is perceived as very helpful no matter the motion style; a not intervening action is seen as unhelpful no matter the motion style; the motion style influences a taking action's perception of helpfulness. Results show that a sine-wave motion style interacts with the taking action of the robothing intensifying the perception of helpfulness of the robothing.

Sub-question 1c: What are the Effects of a Robothing's Motion Styles and Actions on Children's Ascription of Social Qualities to the Robothing?

We found that a robothing's actions have a more significant impact than motion styles, but – again– for the sine-wave motion style. Not surprisingly, children ascribe prosocial social qualities to the giving action of the robothing by significantly selecting adjectives such as generous, helpful, collaborative, happy-go-lucky, and kind. Interestingly, The sine-wave motion style is significantly associated together to the giving action to adjectives such as happy-go-lucky, helpful, friendly, and kind. Again, the sine-wave motion style appears to reinforce the prosocial meaning of the giving action of the robothing. In contrast with the findings of the legibility, the taking action of the robothing associates with antisocial social qualities such as bad, nasty, mean, unfriendly, disruptive, aggressive, and bossy. The not intervening behavior is mainly associated with passive social qualities. Neither the linear nor the jerky motion style have a synergistic effect on the ascription of social qualities.

Question 1: How do Children Interpret the Intention of Different Robothing's Actions to Intervene in a Conflict?

Our sub-questions contribute to answering our main question for Study 5. The legibility findings show that a robothing's actions have the main impact on the way children read and explain the intention of a robothing's behavior. Children consistently read the robothing behaviors in the way we have designed them, as shown by both the legibility findings (open-question about legibility "What do you think Push-one was doing?") and the manipulation check. A similar trend emerges from children's explanation of the intention of the robothing (open-question about legibility, "Why do you think Push-one did what it did?"). However, we find that the taking action of a robothing is considered to have a prosocial intention, especially so when the robothing exhibits a sine-wave motion style. While in literature [319] and in our previous work (Chapter 4, Study 4), a taking away action was considered expressing an antisocial intention, children appear to consider taking away an object to intervene in conflict around said object as helpful to defuse a fight. Interestingly, some of the children do not think that the robothing has intentions of its own. Some children considered the robot as controlled by others. Even though the frequency of these answers is limited, we reflect on our finding. One explanation is that the abstract appearance of Push-one reminded the children of a remotely controlled toy. At the same time, way more abstract and functional robots have been considered as having a mind of its own [228, 7], and this assumption is not in line with the literature of children's tendency to animate objects [3]. We leave explorations of children's perception of a robot's mind to future work.

The most striking result is the interplay of the sine-wave motion-style and the actions of the robots. A sine-wave locomotion to take away an object is seen as way more helpful than with other motion-styles. The findings of the ascription of social qualities show a similar trend regarding the sine-wave motion style. While in line with HRI results [207] and the outcomes of our co-design workshops (Chapter 5), we find this result surprising. A possible explanation is that a curved motion such as the sine-wave motion-style is seen more positively because humans has been found to prefer curved lines of motion [122]. This effect has been found to replicate in HRI as well [302]. Alternatively, the sine-wave motion style could have been interpreted as more hesitant as [207] found in previous work; the hesitance might have mitigated the inherent assertiveness of a taking away action, thereby making the action appear more as a helpful suggestion rather than an assertive coercion to stop arguing. The findings of the ascription of social qualities show a similar trend regarding the sine-wave motion style.

Limitations

Our study suffers from some limitations. First, our experimental methodology (i.e., VHRI) has potential limitations in the ecological validity and

reliability of the results [351]. As already discussed for Study 2 (Chapter 4), a large number of studies have shown that VHRI studies yield similar results in VHRI as live HRI [224, 268, 347, 356, 401]. VHRI guarantees high internal validity by guarantying uniformity of the stimuli. Furthermore, VHRI allowed us to reach a relatively large sample size, which is uncommon in cHRI [25].

Children did not interact with the robothing, which is arguably another pitfall. Children only watched the robothing interact with actors (third-person perspective). An interaction with a third-person perspective appears to yield reliable results in cHRI [268], plus we carefully mitigated third-person perspective's drawbacks by using an over-the-shoulder camera view: participants were able to focus on the robothing, and were not distracted by contextual information. The chosen camera view creates immersiveness [171] in VHRI. Moreover, taking different perspectives for children is beneficial: by taking a third-person perspective, children can more easily discuss how a robot behaves in a particular context, along with its intentions, and social qualities [2].

We chose an off-line video methodology as opposed to an online video methodology to retain the advantages of VHRI (i.e., exploring a wide range of variables, reach a broader set of study participants than in-lab behaviors study, achieve greater internal validity) [151, 356] while opting for a more appropriate method of data collection of our target participants. Research in developmental psychology makes extensive use of in-person exposure to videos [17].

Lastly, while our findings show the interplay of actions and motion styles of a robothing, we did not examine those variables in isolation, nor did we examine all the variables within-subjects. From our previous work (Chapter 4, Chapter 5), we learned that actions and motion styles combined impact children's understanding and perception of a robothing behavior. However, in our previous work, we did not experimentally test the impact of motion styles. Therefore, we decided to focus only on the interplay of the two variables, honing in on the motion styles as between-subjects variables. We considered testing all the variables within-subjects, but we realized after our pilot study that asking children to watch nine videos and reply nine times to the survey would not work with our target group. While VHRI allows us to test several variables, we need to take into consideration that children have a limited attention span. Best practices in cHRI [26] and child-computer interaction [243] suggest keeping sessions at a maximum of 45 minutes. In our study, children already took 40 minutes on average, only to watch three videos and answer three rounds of the survey.

Design Implications

Our study shows that a non-anthropomorphic robothing can communicate conflict-resolution intentions using locomotion and that there is an

interplay between actions and the sine-wave motion style. We show that actions such as (i) giving an object by pushing an object towards children, (ii) taking away an object by pushing the object away from children, and (iii) not intervening by pushing relevant objects in a game at the same time a conflict arises, can be used by cHRI designers to endow non-anthropomorphic robots of legible communication. In particular, we unveil that applying a sine-wave motion style can influence the way people interpret, understand, and perceive a robothing behavior. A sine-wave motion appears to endow the action of a robothing with positive attributes and prosocial intentions. The results of our study cannot explain why the sine-wave motion sorts these effects, but we open avenues to explore the sine-wave motion style for non-anthropomorphic communication.

Methodological Implications

In line with the literature, we find that children experience difficulties in answering “why” questions. Children easily responded to the “what” questions, but often times did not know what to reply to the “why” question as demonstrated by our coding findings. At times, children explained the intention of the robot in the “what question”. Researchers in cHRI should carefully pilot “why” open questions and – as reported in the literature [2, 17]– always couple them with “what questions”.

7.2.7 Study 5: Conclusions

In this exploratory study, we show that a robothing's actions (giving, taking, not intervening) (i) legibly communicates different intentions to intervene in a conflict to children, and (ii) impacts children's perception of the robothing's helpfulness and the way children ascribe social qualities to a robothing. Children perceive a giving and a taking action of a robothing as helpful in a conflict situation. Especially so when the actions have a sine-wave motion style. However, children endow more prosocial qualities to a giving action than to a taking action, which for children embodies antisocial qualities, despite being helpful in a conflict situation. The way the robot moves, the motion style, does not appear to have a particular impact on the way the robothing's actions are understood and perceived. However, we find that a sine-wave motion style interacts with the robothing's actions endowing the actions with prosocial intentions and qualities and boosting the perception of helpfulness of a robothing. While the results of the interplay are difficult to interpret, we think that they relate to the literature about how humans interpret shapes. A Sine-wave is a composition of curved lines which have often been regarded as more harmonious, relaxing, or pleasant—and more in consonance with nature—than straight or broken lines, such as the ones of the other two motion-styles we studied. Despite the methodological limitations, this study contributes to cHRI and HRI interaction

design literature, providing early evidence of the communicative power of non-anthropomorphic locomotion communicating complex intentions in conflict scenarios to children and providing first indications of the interplay between a robothing actions and the sine-wave motion style on children's perception of a robothing.

7.3 CHAPTER CONCLUSIONS

In this chapter, we have explored the interplay of actions and motion styles for Push-one for the first time. Initially, in our conceptual framework and design principles, we did not contemplate the “expressivity” of a robothing behavior. The theory suggested that robothing actions are sufficient to communicate a robothing intention without any motion-style. However, our co-design activities with children indicated that there is an interplay between motion-style and actions. Therefore, we revised our design principles to contemplate individual motion styles on top of a robothing’s actions. In this chapter, we empirically investigated this interplay. We show that indeed there is an interplay, especially for the sine-wave motion style. The sine-wave motion style appears to spin the perception of an action positively. Simultaneously, we unveil that a robothing’s actions have a more substantial effect on how children interpret and perceive a robothing’s behavior. While our findings are in line with the literature related to locomotion styles [207, 302], we cannot provide a definitive answer regarding this aspect of the design of non-verbal behavior. We provide a possible explanation, relating our findings to the theory of human perception, which states that humans prefer specific “shapes” of objects and motion [122].

The results reported in this chapter contribute to two main research questions of the dissertation (RQ3 —How should the non-verbal behavior of low/non-anthropomorphic robots be designed to communicate a robot’s intention to children? And RQ4 —How do children interpret and perceive a low/non-anthropomorphic robot’s non-verbal behaviors in play?) by shedding light on how children interpret an action of a robothing to intervene in the conflict. Moreover, the results contribute to the dissertation’s overarching research questions by providing rich insights into the interplay of motion-styles and actions. The chapter offers room for reflections about what it means to design non-verbal behavior of low/non-anthropomorphic robots in ‘*human terms*’. We have shown that a robothing’s actions that might at first glance appear merely functional, such as the locomotion of a robothing pushing an object, are interpreted as a helpful prosocial action in the unfolding interaction. Motion-styles have an impact on building a ‘*character*’ of a robothing. Still, our findings—even if limited—suggest that distinguishing functional and expressive motion for low/non-anthropomorphic motion might be superfluous. Simultaneously, the study’s findings suggest that future work should focus on untangling the interplay between actions and motion-styles of a low/non-anthropomorphic robot. The interplay between the way an action is delivered and the action itself might be more complex and multi-faceted than expected. We will discuss more on this in Chapter 9.

Overall, Study 5 informs our subsequent investigation of the effect of these robothing’s behaviors on cHRI. Push-one’s actions to intervene in a conflict legibly communicate to children in conflict scenarios, especially the giving and taking action stylized with the sine-wave motion. Even if

both actions are perceived as helpful in a conflict situation, children still consider them bearing different social qualities. As a result, these robothing behaviors might have different effects on children's prosocial behavior and collaboration. We investigate how giving versus taking action, both stylized with the sine-wave motion, impacts cHRI during collaborative play conflicts.

WHEN A ROBOTHING IS PROSOCIAL IN A CONFLICT OR COERCIVE: EFFECT ON CHILDREN'S PROSOCIAL BEHAVIORS AND PERCEPTION OF COLLABORATION

“Human beings routinely help others to achieve their goals, even when the helper receives no immediate benefit [...]. Such altruistic behaviors (toward non-kin) are extremely rare evolutionarily, with some theorists even proposing that they are uniquely human.”

Micheal Tomasello (2006)^a

^a I suggest to listen to **The softness of the present** and **Zodiac** by The Comet is Coming while reading this chapter.

Chapter 8 reports a Wizard-of-Oz cHRI study (Study 6) to evaluate the effect of a robothing on children's prosocial behavior and collaboration in play. In the previous study, Study 5 (Chapter 7, we have evaluated how different Push-one behaviors to intervene in conflict communicate to children and the interplay between a motion-style and an action. From the results of Study 5, we select two actions (i.e., giving and taking) underlining each a different strategy to intervene in a conflict, and one motion-style (i.e., sine-wave). In this study (Study 6), we sought to investigate how a robothing intervening in conflict either with a prosocial strategy or with a coercive strategy impact children's prosocial behaviors and collaboration after the interventions and the children's perception of helpfulness of and collaboration with the robothing and the other children. This chapter sheds light on Push-one's effect in real-life in-the-wild-interaction with children. We report results and discuss the theoretical and design implications of the conclusive study of the dissertation. We find that children perceive a robothing and the other child in the game as more helpful and collaborative when the robothing intervenes in a conflict with a prosocial strategy. Children share and help each other more after the robothing has exhibited a prosocial behavior.

The chapter is based on the following publication (in preparation):

Zaga, C., Jung M. E., Truong, K.P. and Evers, V. *My New Toy is a Robothing: Designing Non-anthropomorphic and Non-verbal Robots to Promote Children's Collaboration Through Play.* *ACM Transactions on Human-Robot Interaction* (in preparation).

8.1 CHAPTER INTRODUCTION

Play is fun but also learning for children. Through play, children learn how to regulate their prosocial behaviors to collaborate with others (among many other things). The dissertation's primary focus is to support children in natural ways to learn about collaboration. Real-life practice through play with peers is the best way for children to master collaboration, but opportunities to do so are scarce (see 1 and Chapter 2). We posit that by leveraging the reciprocal and prosocial dynamics during naturally occurring interactions with a playful robot toy, we can provide play-based opportunities to train collaborative skills and nurture prosocial behaviors beyond school-based interventions and beyond the current social robotics status quo (i.e., tutoring robots).

What effect a robothing has on children's behavior while engaged in collaborative play, then? Thus far, we have empirically unveiled how a robothing could communicate in *human terms to children* by leveraging its non-verbal actions. We have enabled low / non-anthropomorphic robots and Push-one to communicate prosocial (and antisocial) intention to intervene in play with few degrees of freedom and non-verbally. To this end, we have studied how children parse a robothing behavior, how they perceive it in a context (Study 2 and Study 5 in particular).

About this Chapter

Now, we shift the focus on *understanding what impact a robothing has on children's behaviors* when interacting with them in collaborative play. We have provided early insights about the behavioral effects of interacting with a robothing in Chapter 4, learning about the effects a robothing has on direct and direct reciprocity and group dynamics. Building on those insights and the co-design workshop, we have developed Push-one, a robothing that aims to intervene in children's conflicts during collaborative play. We envision Push-one as a toy robot that exhibits prosocial, antisocial, and passive actions in collaborative play to support children's prosocial responses when experiencing conflicts about objects' possession. Push-one leverages the reciprocal and prosocial dynamics in collaboration to stimulate children to be prosocial. It does not tell children what to do or how to behave, but it leaves children reflecting on what action to take. Chapter 7 gathered empirical results about how well the Push-one behaviors communicate a prosocial, antisocial, and passive intention and what role motion-styles have. However, we do not know how children react and perceive the robot when playing with it in real-life situations. This chapter sheds light on Push-one's effect in real-life in-the-wild-interaction with children. We empirically examine how Push-one could support the emergence of prosocial behaviors in children intervening with a prosocial or coercive strategy in conflict arising in collaborative play.

Study 6

We focus on a robothing's intervention in conflict around the possessions of objects. We further develop the scenarios introduced in Chapter 6 and use the behaviors evaluated in Chapter 7. We select two actions, giving and taking, of a robothing with a sine-wave style, which, according to the results

in Chapter 7, is well understood by children. Giving and taking behaviors underline a prosocial or antisocial conflict resolution strategy; hence, we want to compare them to assess their effects on children. Therefore, this chapter tackles the fourth *RQ4. How do children interpret and perceive the non-verbal behavior of low/non-anthropomorphic robots in play?* and sixth research question of the dissertation *RQ6. What are the effects of a robothing behavior on the prosocial behavior and collaboration of children in play?*. In the chapter, we tackle these questions with a behavioral study. In a mixed-method WoZ study, children play with a robothing with either a prosocial (i.e., giving) or antisocial (i.e., taking) conflict resolution strategy. We investigated how a robothing intervening in conflict either with a prosocial strategy or with a coercive strategy impact children's prosocial behaviors and collaboration after the interventions and the children's perception of helpfulness of and collaboration with the robothing and the other children. The chapter report the main findings of the study and discusses the design and theory implications.

8.2 STUDY 6: THE EFFECTS OF A ROBOTHING CONFLICT RESOLUTION STRATEGY ON CHILDREN'S PROSOCIAL BEHAVIORS AND PERCEPTION OF COLLABORATION

Collaborating involves many social dynamics. In collaboration, at least two individuals interact with each other while collaborating, attuning each other behaviors towards a common goal. Conflict is one of the central dynamics of collaboration. A conflict could be beneficial for team dynamics, but it can also hinder it. Conflicts are challenging to deal with for everybody, but especially children find it hard [319] to tackle them. As we have seen in Chapter 2, conflicts in childhood are disputes involving pairs or groups of three or more children [323] arguing about either interpersonal or object-oriented issues (e.g., the possession of an object). When children have conflict, they cannot get what they want: they might want a specific object or try to change another child's behavior. In either case, this desire is not fulfilled because another child is opposing it, or it is not clear what action to take.

When facing a conflict, children resort to various strategies (as we have seen in Chapter 2 and Chapter 7) to deal with the conflict and continue a shared task. Among the available strategies, prosocial and coercive strategies are the main ways children tackle conflicts. For example, either a child share resources or help another instead of arguing (prosocial strategy) or force another to stop or change his behavior (coercive strategy) [248]. While both strategies can be successful, a prosocial strategy, which entails a prosocial behavior to alleviate a negative state of another, typically enables a series of positive dynamics: positive perception of the peers, reciprocity of the prosocial behaviors, more prosocial or collaborative behaviors [248, 97, 300]. While children learn how to behave when facing a conflict by merely playing with peers, it is often not automatically happening. Children do not always find a way to deal with interpersonal issues and regulate behaviors and emotions to collaborate without arguments. Robotic technology could play a role in supporting children's learning of the prosocial and collaborative skills needed to play together and deal with conflicts by intervening in play. Playful paradigms favor the natural way children learn to collaborate through experience in play.

Motivation

Most interventions to support children's collaboration and nurture positive resolution of conflicts are based on either scaffolding, instructions, or gamified exercises. Also, digital technology and robotics interventions have focused on replicating school-based interventions, often having a limited impact (See Chapter 2). We believe that social robots, particularly mobile social robots, could provide playful interventions that support the way children naturally learn about collaboration. However, play-based opportunities for training collaborative skills and nurture prosocial behaviors are less explored in cHRI.

To address this gap, we explore playful paradigms and intervention. In particular, we explore how low/non-anthropomorphic robots, a robothing, could support collaboration and prosocial behaviors by playing with children and exhibiting simple actions underlining conflict resolution strategies. Building on theories of prosocial interaction [97], we posit that the mere exposure to the action of helping or sharing of a robothing in play leads to reciprocity and a greater tendency to be prosocial in the short and long term [101]. Actions such as sharing establish the prosocial norm and prompt reciprocal dynamics in a group [96]. Prosocial and reciprocal dynamics promote collaboration, even when collaboration is challenging [248], like in conflicts. Interacting with a robothing that exhibits a prosocial or antisocial strategy could impact children's prosocial behaviors towards the robot and other children, thereby influencing conflict resolution. Moreover, it could impact the way children make sense of collaboration: they might perceive the robothing and the other children differently, hence changing their attitudes in collaborative play.

We sought to investigate how a robothing intervening in conflict with a prosocial strategy or a coercive strategy impacts children's prosocial behaviors and collaboration and the children's perception of helpfulness and collaboration with the robothing and the other children. We investigate these effects in an ad-hoc experimental protocol to elicit a conflict about the possession of collaborative play resources. We create a scarcity of resources in a game. For the robothing to intervene in the conflict, we operationalize a prosocial strategy as an act of "giving", sharing objects to stop an argument over objects' possession. We compare a prosocial strategy to a coercive strategy, operationalized as an act of "taking", forcefully suggesting to stop an argument over the possession of objects by removing the cause of the conflict. We expect there is going to be a difference between a prosocial and coercive strategy. As we have seen in Chapter 7, a prosocial strategy has a positive impact on the perception of the helpfulness of a robothing. Literature shows that an agent's prosocial behavior might also positively impact the perception of collaboration with the agent and the other people involved [284]. Therefore, we hypothesize:

Hypotheses

- **H1.** The prosocial strategy will increase children's **a)** post-interaction perception of helpfulness of the robothing **b)** the perception of collaboration with the robothing —more than a coercive strategy for conflict resolution;
- **H2.** The prosocial intervention will increase children's **a)** post-interaction perception of helpfulness of the other child in respect **b)** the perception of collaboration with the other child —more than a coercive strategy for conflict resolution.

Moreover, our previous work (Study 3, Chapter 4) and literature [97, 284, 91, 248] show that when experiencing prosocial behaviors in conflict, chil-

dren tend to exhibit more prosocial behavior, helping in the game, sharing resources, and collaborating more. Thus, we hypothesize:

- **H3.** The prosocial strategy will increase children's prosocial behaviors towards the **a)** other child and **b)** the robothing after the intervention more than a coercive strategy for conflict resolution.

We test our hypothesis in a one by two (prosocial strategy vs. coercive strategy) mixed-method between-subject WoZ study with dyads of elementary school children.

8.3 RELATED WORK: ROBOT'S IMPACT ON CONFLICT RESOLUTION AND COLLABORATION

Increasingly researchers are investigating how technology could nurture prosociality and collaboration [269, 187]. Researchers have started to offer solutions to support children's collaboration and resolve conflicts [336, 335, 324]. In particular, HRI featuring embodied technologies that can interact in the space and with an object are ideally positioned to deliver an intervention that is pervasive and can go beyond the boundaries of classical school-based interventions. Compared to other technology and existing educational programs, robotic technology offers a convenient opportunity to extend children's development of conflict resolution skills outside school.

According to a recent review [269], HCI and HRI have focused on studies in controlled settings to replicate classical psychological experiments from game-theory (e.g., the Desert survival task), conversations, and playing games or doing tasks with a robot. Research in HRI with adults shows that robots are seen as potential collaborators and can have an effect on collaborative dynamics [149] and shaping teammates attitudes towards the robot and each other [353]. Correia et al.[63] explore the prosocial facets of collaboration in games with adults. Their study unveiled that a robot behaving in a prosocial way was perceived as more favorable than a selfish robot, impacting teammate selection, and perception of competence.

Related work on conflict

As conflicts are part of collaborative interaction, HRI research investigates how a robot can influence favorable conflict resolutions. Jung et al.,[186] has shown that a robot in the role of mediator of conflict can actively contribute to regulate emotions of the team and influence the human team members to resolve conflict positively. Most of the HRI studies make use of verbal strategies to steer collaboration dynamics and promote conflict resolution. However, non-verbal behaviors at large [40] and primarily actions in the task [183, 187] play an essential role in collaborative interaction, and they have a significant impact on dynamics of conflict resolutions. For instance, Jung et al., [187] have found that the resource distribution behaviors (that is, sharing objects) in a construction task shaped people's perception of the team and the robot and influenced the collaboration dynamics. While HCI has shown the potential of interactive technology to support collaboration and conflict

resolution, there is not much research in cHRI on the matter. Social robots appear to shape children's collaborative dynamics [354] positively. Shen et al., [324], in a study with young children, have demonstrated that a robot mediator can positively steer children towards ending conflict-related to toy possession. However, all these interventions focus on tutoring paradigms, excluding play from the interaction. Most of the robots used in cHRI have human-like forms and behaviors; therefore little is known about how a low/non-anthropomorphic robot will sort an effect with non-verbal and playful interventions.

Therefore, little is known about how the interaction with a robot in play impacts reciprocal dynamics and collaboration. We know from the literature that adults are impacted by the prosocial behavior or the strategy a robot adopts to resolve conflict. We know that children consider the behavior of a robot social [67] and that effects for human-human interaction replicate in some instances in human-robot interaction [291]. However, we do not know how a robot can achieve such effects only through playing with children. This study – to the best of our knowledge is one of the first to empirically explore the opportunity of supporting conflict resolution promoting prosocial behaviors and collaboration with a low/non-anthropomorphic robot communicating non-verbally.

8.4 METHODS

In a one by two (prosocial strategy vs. coercive strategy) mixed-method between-subject WoZ study, we examined the effect of a robot conflict resolution strategy (prosocial strategy vs. coercive strategy) on (i) children perception of helpfulness and collaboration (both of the robot and the other child), (ii) on children's prosocial behaviors, (iii) children tendency to share the reward of the game and (iii) to help the robot after the intervention.

8.4.1 Participants

Dyads of elementary school children ($n = 58$ $n(\text{dyad}) = 29$ $m(\text{age}) = 10.41$ $sd(\text{age}) = 1.06$ $n(\text{girls}) = 24$) from a public school in the east of The Netherlands participated in the study. Participants were randomly assigned to the two experimental conditions, i.e., prosocial ($n = 30$, dyads = 15) and coercive ($n = 28$, dyads = 14) from lists provided by the teachers of the school.

We asked the teachers to provide a list per elementary school grade (called Group 6, Group 7, Group 8 in the Netherlands). The goal was to pick dyads from each grade randomly but not to have mixed grade dyads. The rationale behind this choice was to assure that participants were not too dissimilar in their cognitive, social, and motor abilities. Moreover, we

wanted to mitigate the possible confound related to the degree of friendships between the participants. To this end, we asked the teachers to create subgroups of six children in each of the lists, avoiding to pair children that are known to be best friends with each other in the subgroup. We picked dyads randomly from the subgroup. The resulting dyads of participants were either mixed or the same gender. Two months before the experiment, participants were introduced to the Push-one robothing in two instances. Participants saw what the robothing could do and its main ways to interact with children. Moreover, 90% of the participants had experiences with various robot platforms before the experiment. Therefore, we consider that participants experience a minimal novelty effect.

We assessed the level of empathy of each of the participants before the commencement of the experiment, as participants' degree of empathy might play a role in the way children perceive and respond to the robothing's conflict resolution strategies (see Measure section, below and Appedix [A](#)). We did not find any statistically significant differences in participant's empathy level, neither between-subjects nor between children in each dyad. Participants' scores show a moderate to a high level of empathy.

8.4.2 *Ethics*

The ethical committee of the Faculty of Electrical Engineering, Computer Science, and Mathematics of the University of Twente and the ethical committee of the elementary school of the children both approved the study. We developed the conflict elicitation and the protocol of the study in close collaboration with the teachers of the school. The goal was to devise a conflict elicitation protocol that would guarantee the emotional well-being of the children.

Children legal guardians participated in an informative session with the researchers and the teachers two months before the experiment to ask questions about the robothing, protocol, and measures. After that, the children's guardians signed an informed consent form. Children participated in two informative sessions with the researcher's two months before the study. During the sessions, we did not disclose the goal of the study nor the fact that the robot is not autonomous. We fully informed the children about the format of the study and their rights to end the study at any given moment.

Before starting the study, children gave their verbal assent to participate in the study to the researchers. Only two children refused to continue the study due to personal reasons; we deleted their data. At the end of the data collection, we visited the school to debrief children about the study's scope thoroughly. To address deception issues, we informed children that a researcher remotely controlled the robothing, and we showed the children how the robot works.

Figure 68: The figure illustrates the conditions of Study 6. The figure provides details about the way conditions were operationalized.

Robothing, Robothing Behaviors and WoZ

The Push-one robot is the robothing used in the study (see Chapter 6 for the details about Push-one's design). To operationalize the prosocial and coercive conflict resolution strategy, we selected two of the robothing behaviors examined in Study 5 (Chapter 7). The prosocial strategy is operationalized as giving action with a sine-wave motion-style. The coercive strategy is operationalized as taking action with a sine-wave motion-style. The results of Study 5 showed that both actions convey the intended prosocial and coercive intention. The sine-wave motion-style is chosen as it appears to make the perceived prosocial intention of the giving action stronger and the perceived antisocial intention of the "taking" action milder. As explained in the Introduction to the study, we are interested in testing how two conflict resolution strategies that children might have different effects on children's prosocial behavior and perception of collaboration, but we are not interested in implementing an aggressive behavior.

The action of **giving** (see Figure 68) underlines a **prosocial strategy** for conflict resolution: sharing objects to stop an argument over the possession of objects. The prosocial strategy protocol was as follows: In our scenario, the robothing gives an object of its to children 50 seconds after children face an adverse situation in the game that can cause conflict. Children both need the same piece of the puzzle to finish their puzzle, but they have only one at their disposal. The robothing has an extra one of that kind (same shape and color), at it pushes the puzzle piece towards children and delivers it to them. The robothing stops in front of the children, in a given area, with the piece of puzzle children need and then goes back to its position. Conversely, the action of **taking** (see Figure 68) underlines a **coercive strategy** for conflict

Figure 69: The figure details the sequences of actions after the conflict is elicited. The pictures show the giving condition.

resolution: forcefully suggesting to stop an argument over the possession of objects by removing the cause of the conflict. The coercive strategy protocol was as follows: In our scenario, the robothings pushes away the piece of puzzle children are conflicted about and then goes back to its position. Should one of the children take the piece of the puzzle they are conflicting about (the only one available for them) and use it for his/her puzzle, the robothing takes away the object from the child's puzzle. Both the actions are delivered with a **sine-wave motion-style**: the robothing drives forward in continuous sinusoidal curves.

We set a fixed amplitude of rotation at 300 degrees with a velocity of 1 km an hour. Push-one is a remotely controlled robothing, the researcher controls when the robothings moves, towards which object or person it moves, but not the pre-programmed motion style. A hidden remote operator (the "Wizard of Oz") controlled the robothing with a radio controller. The remote operator used the live video feed of an action camera placed on the room ceiling. We followed all the guidelines established in HRI for Wizard of Oz studies [297]. The same wizard ran all sessions following the behavior protocol, as explained above. The wizard had six months of experience using the robot and fifteen days of training at the study's location. Although reproducing perfectly identical motion was difficult due to the floor traction limitations and the variability of the children's behavior in the game, the protocol and the extensive training ensured relatively consistent behavior.

Game and Materials

Below, we detail the game was devised for the study and the materials used.

- **Game.** We designed a puzzle-game with rules for the study. The game created a scarcity of resources that put children in a conflicting situation. The game is based on Tangram puzzles, dissection puzzles consisting of seven geometric pieces assembled to form a large number of shapes. We called the game 'The Master of Tangram'. In the game, dyads of children play independently but share resources (i.e.,

Figure 70: The figure illustrates the puzzle outline presented to the children.

Tangram pieces) and play in a shared space. Both children make the same shape of a given figure, but they are faced with a scarcity of pieces: at some point in the game, both children need the same puzzle piece, but only one is available for them. We implemented specialized game mechanics to create a scarcity of resources. First, to take a piece of the puzzle, children needed to declare what piece they will take and touch it with a finger. Children cannot take a piece until both players have declared the piece they will take. This mechanic was devised to make sure there were precise turns in the game and that both children maintained the same pace in the game. Children are not free to choose the piece they want at each turn: They received eleven cards from the ‘Master of Tangram’, which indicated the piece the child should draw at every turn. We devised this game mechanic to control the piece of the puzzle was taken by the children at every turn. Children needed the same seven pieces each to finish the puzzle. We provided the children with twenty pieces of Tangram puzzle: thirteen pieces that the children needed for the puzzle and seven that children do not need directly but can store as a reserve. Therefore, children missed one of the pieces needed to finish the game. The last piece children need to draw from the heaps of pieces is the one both children need to finish the puzzle. Potentially, a child can take the last piece available and leave the other child without the possibility to finish the game. Alternatively, both children remain conflicted on whether to take it or not and might leave it there. Potentially, children each have in their reserve a piece that, combined with one piece of the other child’s reserve, could substitute the missing piece. We devised to see whether children would collaborate as a way to go around the scarcity of pieces. Hence, we devised this game mechanic to enable collaboration, possibly.

- **Materials.** We used commercially available Tangram puzzles (See Figure 70) and we prepared ourselves the eleven cards with the ‘Master of Tagram’ instructions. Two tablets were used to administer the pre-and post-interaction surveys. Children could read the questions

and type the answers on the tablet. The surveys were developed on SurveyMonkey ¹. We designed a survey attuned to children's cognitive and social development and their reading and comprehension level (i.e., 7 to 12 years old). We accurately follow recommendations of survey developments for children [242]. Questions were successfully piloted with 20 children and devised in collaboration with teachers.

8.4.3 *Set-up and Study Protocol*

Here, we describe the set-up and the protocol of the study.

- **Set-up.** The study took place in a dedicated room of the school, reserved for the study. In the room, we created four areas: an experimental area, a WoZ area, a survey area, a 'share test' area. The room was familiar to the children but set apart from the classrooms in a quiet space. In the experimental area, we delineated the experimental area's perimeter clearly, with fixed positions for the robothing, participants, and game. We equipped the experimental area with an action camera on the ceiling, an HD video-camera, Tangram Puzzles, and game cards. The actions camera provided the sessions' live feed to the WoZ operator, while the HD camera audio-video recorded the game sessions. The WoZ area was in the same room, but the WoZ operator was hidden behind several cabinets out of children's vision. In the survey area, participants familiarized themselves with the game and filled in the pre-and post-surveys. To avoid children influencing each other answers, children sat at the same table at least 1,5 meters apart. The researcher who facilitated the sessions sat between the children. We equipped the survey area with two tablets and Tangram puzzles. In the 'share test' area, children sat each on a table to experience a forced-choice behavioral measure of sharing.
- **Protocol.** Two researchers carried out all the experimental sessions. One researcher was the leading facilitator of the session; the other was responsible for the operation of the robothing. Each session had the following protocol: the facilitator welcomed the children in the room and let them re-familiarize themselves with the robothing for 15 minutes. The robothing moved back and forth, pushing objects towards the facilitator and then away from the facilitator. The facilitator explained the robothing could play with Tangram puzzles and that we wanted to invite the children to play. After the initial familiarization with the robothing, children sat in the survey area to answer the pre-test survey. As soon as both children finished, the facilitator explained the Master of Tangram game rules to the participants and let them play a trial game. During the trial game, we did not create a scarcity of

¹ <https://www.surveymonkey.com/>

resources to avoid to prime the participants. The trial game ended with both the participants being able to finish the game. After that, we invited participants to play the game in the experimental area. We explained that Push-one would also play the game with its puzzle pieces, while participants would have to pick puzzle pieces from the same heap of pieces placed between the children. The facilitator sat next to the participants to guarantee their safety and attend to their wellbeing. The facilitator was instructed not to help or talk to participants and not explain the reason for the scarcity of resources, even if participants asked. With the eleventh round, the conflict elicitation started. Participants had only one piece left, which they both needed. After fifty seconds, the robothing intervened with one of the strategies. We let participants play an extra 7 minutes after the intervention of the robothing to discern the intervention's behavioral effects. After 7 minutes, no matter if participants were finished with the puzzle or not, the facilitator escorted them to the survey area to administer the post-questionnaire. As soon as one participant was done with the survey, the facilitator escorted the participant to the 'share test' area to do the share test. Once the participants were done with the share test, we asked the participants to say goodbye to the robothing individually. While one participant waited outside the room, we performed a help-test with the other (similar to Study 4, Chapter '4) and then the other way round. Once finished with the help-test, the facilitator escorted the participants to their classrooms.

8.4.4 Measures

To investigate our hypothesis, we used quantitative and qualitative measures. Measures are attuned to children's cognitive development. We administered a survey before the experimental sessions (i.e., pre-survey) and a survey after the experimental session (i.e., post-survey) with quantitative measures. We administered two forced-choice behavioral measures to assess sharing and helping tendencies of the children *after* the game. Then, we conducted behavioral observations to discern whether children exhibit prosocial behaviors *during* the game *after* the robothing intervention.

The scope of the **pre-survey** was to gather demographics information, administer the Empathy Index Scale (explained in the participant's session) and an item about the perception of helpfulness of the robothing (same item from Study 2 and 5). The items of the pre-survey were as follows:

- **General information:** we asked demographics information and whether participants have played with a robot before;
- **Empathy Index:** We administered a validated instrument (Index of Empathy for Children [45]) to assess children's empathy, translated to Dutch (we performed forward and backward translation to maintain

equivalence of the test questionnaire in Dutch). We presented the children with twenty-two items which they could score with 'yes' or 'no'. See Appendix A for a list of the items in English.

- **Perception of Helpfulness (Pre-interaction):** We asked '*In your opinion, how helpful is Push-one?*' to discern the perception of helpfulness of the robothing prior to playing with the robothing and compared it the perceptions after playing; the 5 points Likert scale question was anchored from *Not helpful at all* to *Very Helpful*. The question was used and validated in our prior work.
- **Perception of Helpfulness of the other child (Pre-interaction):** We asked '*In your opinion, how helpful is the other child?*' to discern the perception of helpfulness of the other child prior to playing with the robothing and compared it the perceptions after playing; the 5 points Likert scale question was anchored from *Not helpful at all* to *Very Helpful*.

The scope of the **post-survey** was to evaluate participants' perception of helpfulness of the robothing and the other child, and perception of collaboration with the robothing and the other child. The helpfulness items derive from our previous work and have demonstrated high reliability and low ceiling effect (widespread with the children population). The items were as follows:

- **Perception of Helpfulness (Post-interaction):** We asked '*In your opinion, how helpful was Push-one in the game?*' to discern the perception of helpfulness of the robothing after playing the game. The item is a 5 point Likert scale question was anchored from *Not helpful at all* to *Very Helpful*.
- **Perception of Helpfulness of the other child:** We asked '*In your opinion, how helpful was the other child in the game?*' to discern the perception of helpfulness of the other child after playing the game. The item is a 5 point Likert scale question was anchored from *Not helpful at all* to *Very Helpful*.
- **Perception of Collaboration:** We asked '*In your opinion, how much have you collaborated with Push-one in the game?*' to discern the perception of collaboration with the robothing in the game. The item is a 5 point Likert scale question was anchored from *Not at all* to *Very much*.
- **Perception of Collaboration with the other child:** We asked '*In your opinion, how much have you collaborated with the other child in the game?*' to discern the perception of collaboration with the other child in the game. The item is a 5 point Likert scale question was anchored from *Not at all* to *Very much*.

Codebook for Behavioral Observations		
Code	Definition	Examples
Prosocial Behavior	A prosocial behavior is the alleviation of a negative state of another. One can alleviate an instrumental need by helping solve a puzzle or alleviate a material need by sharing a resource.	<ol style="list-style-type: none"> 1. A child takes the puzzle piece the robothing brings, but then gives it up and help the other child to solve the puzzle. 2. A child points towards the pieces another child needs to complete the puzzle. 3. A child sits next to the other child struggling to finish the puzzle to help. 4. A child gives one of his extra pieces to help the other child finish the puzzle
None	No prosocial behavior means not acting on the negative state of another. No action is taken to alleviate an instrumental need or material need.	<ol style="list-style-type: none"> 1. A child does not interact with the other. 2. A child continue working on his own puzzle. 3. A child looks at the other child but does not interact. 4. A child stops working on its puzzle and does not interact with the other child

Table 29: The table details the codebook used to analyze the behavioral responses of children after the robothing's intervention in the conflict. From the right, the code, then the definition and lastly examples from the audio-video recordings.

To discern how the robothing impact children's prosocial behaviors, we developed two **forced-choice behavioral measures**, as follows:

- **Share test:** The Share test was developed following the protocol of [340]. Participants were presented with six stickers, which represented the reward for playing the game, and three envelopes. Participants were told that they could keep all of the stickers and put them in the envelope with their name or share any number (1–6) with the other children and/or Push-one by placing them in the respective envelope. Participants were given no further indications and made their sharing choices outside the view of the facilitator. We pre-tested the share test with 20 children, and all the children found the test clear.
- **Help Test:** The help test was developed on the basis of [284] and our previous work (Chapter 4). Participants were presented with a difficult situation for Push-one. The robothing cannot drive forward but goes back and forth. There is a battery pack with written on top 'Push-one extra battery' in front of Push-one. The facilitator said: 'Now, it is time to say goodbye to Push-one. Oh, it looks something is going on with Push-one'. Then the facilitator waited for 3 minutes to see whether the children would help the robothing to reach the battery pack. We successfully pre-tested the Help-test with 20 children.

We carried out quantitative **behavioral observations** to evaluate if the children are prosocial with each other after the robothing's interventions.

8.4.5 Data Analysis

We carried out twenty-nine sessions in three months of data collection. Every session lasted, on average, 55.05 minutes included familiarization and time to administer surveys and forced behavioral measures.

After inspecting the data, we added one exploratory variable with two levels to consider in our data analysis: the child's action; after the conflict elicitation and before the intervention of the robothing, some participants have taken the last piece available for themselves. After the data collection, we wonder if the participants' action possibly affects the perception of helpfulness and collaboration items, on the forced-behavioral choices, and the behavioral observation. Twenty-three participants took the last piece of the puzzle in the conflict situation, and thirty-five did not. Divided over the conditions, in the prosocial strategy condition, eleven participants took the triangle, and nineteen did not; in the taking condition, twelve participants took the triangle, and sixteen did not. This variable is exploratory, not confirmatory. Considering this variable, we analyzed the data as follows:

- Three-way mixed analysis of variance (ANOVAs) were conducted to evaluate the effects of a prosocial or coercive strategy and children taking or not taking puzzles pieces in the conflict on the pre-and post-evaluation of the helpfulness of the robot and the helpfulness of the child;
- Two-way analyses of variance (ANOVAs) were conducted to evaluate the effects of a prosocial or coercive strategy of a robothing and children taking or not taking puzzles pieces in the conflict elicitation on children perceived collaboration with the robothing and the other child;
- The Pearson Chi-Square test of associations has been carried out to analyze the share and help test; we counted the occurrence of help in the help test and the number of stickers to self (child), other child, and robothing. In the help-test, we considered it a helping behavior only when the child brought the battery pack towards the robothing; all the other reactions were not considered helping.
- Two independent coders deductively annotated the behaviors of the children in the game after the robothing intervention. We inspected the audio-video recording, and we identified the presence or not of prosocial behaviors after the intervention. We started from the definition of prosocial behavior of [91] and formulated the following definition: a prosocial behavior is the alleviation of another's negative state. One can alleviate an instrumental need by helping solve a puzzle or alleviate a material need by sharing a resource. We coded the occurrence of prosocial behavior as per the definition above, but not the types of behaviors. We structured a unified codebook following guidelines from [239] with a code, a definition, and examples. The answers were coded iteratively and independently; then, we compared the agreement to resolve any mismatches. After every iteration, we updated the codebook accordingly (see Table 29). The coding was binary. We coded the presence or absence of prosocial behaviors

Codebook for Open-Question: Why did Push-one did what it did with the puzzle piece?		
Code	Definition	Examples
Prosocial	An intervention to help another in the game. An intervention with a costly behavior for who intervenes, such as giving up resources to ease the situation.	<i>"Ik denk dat hij wilde helpen de situatie op te lossen"</i> <i>Translation: I think he wanted to help solve the situation</i> <i>"Omdat ik geen oranje stukje had. De robot wilt helpen"</i> <i>Translation: "Because, I did not have an orange piece. The robot wanted to help"</i>
Coercive	An intervention to forcefully ease a situation by removing an object that is contended or that people are conflicted about.	<i>"omdat hij vind een ruzie niet leuk. om ons genoeg te zeggen"</i> <i>Translation: because he does not like the situation. To tell us enough</i> <i>"Zodat wij geen ruzie zouden krijgen over het stukje. Om ons te stoppen."</i> <i>Translation: So that we would not have a conflict about the piece. To stop us.</i>
I don't know	The answer show that the participant does not know why	<i>"geen idee"</i> <i>Translation: I don't have a clue</i>

Table 30: The table details the codebook used to analyze the open-question: 'Why did Push-one did what it did with the puzzle piece?' for our manipulation check. On the right, the codes used to annotate the corpus of answers. In the center, the definition used for each code. On the right, examples taken from the corpus of answers. Please note, the answers are not corrected, but copied as they are with typos and grammatical errors.

per child. We carried out four independent iterations on 100% of the corpus before reaching a saturation point. Every coder had a document with the codebook and a list of the sessions where coders noted the absence of prosocial behaviors. We carried out a Pearson Chi-Square test to statistically discern the degree of association of the coding and the experimental conditions. We analyzed standardized residuals to interpret the results of the test. Standardized residuals show represent the error between the observed frequency of the counts (i.e., the frequency of the results) and the expected frequency (i.e., what a Chi-square model predicts). A positive value of the standardized residuals indicates more counts than expected and a negative value that there are fewer counts than expected. A standardized residual value higher than 1.96 or lower than -1.96 for either more or less expected counts is considered significant at $p < 0.05$.

- The Empathy Index items reached a Cronbach's alpha of .701 in line with the results in the literature [45]; however, we did not find any difference between children's scores; therefore, we did not perform any exploratory test to discern whether the degree of empathy of has an impact on the other results.

Manipulation Check

A manipulation check was conducted to evaluate whether the children perceived prosocial strategies and coercive strategies correctly. To evaluate the experimental conditions' manipulation, we asked the children what action the robot is doing and why. We have learned from our previous work (Study 5, Chapter 7) that both questions are needed to discern how children interpret a robot behavior.

We asked 'What action was Push-one doing in the game' and participants could select either 'giving an object to the children' or 'taking an object away from the children'. The results show (see Table 31) that the children overwhelming identified the actions of the robot correctly, and there was a significant association between the choice of the children and the conditions. ($\chi^2 = 55.98, d = 2, p = < .000, \phi = .983, p = < .000$).

Perceived as	Condition	
	Prosocial	Coercive
Giving	29	0
Taking	0	27
Nothing	1	1

Table 31: Manipulation check counts results of the question: 'What action was Push-one doing in the game'

We administrated an open item to ask why the robothing did what he did 'Why did Push-one did what it did with the puzzle piece?'. We wanted to discern if children understood the prosocial or coercive motive of the robothing. Two researchers coded the answer 'prosocial' or 'coercive'. We coded the answers deductively starting from our definition of prosocial conflict resolution strategy (i.e., an intervention to help another in the game). It is an intervention with a costly behavior for who intervenes, such as giving up resources to ease the situation) and coercive conflict resolution strategy (i.e., an intervention to forcefully ease a situation by removing an object that is contended or that people are conflicted about). We structured a unified codebook following guidelines from [239] with a code, a definition, and examples. The answers were coded iteratively and independently; then, we compared the agreement to resolve any mismatches. After every iteration, we updated the codebook accordingly (see Table 30). We carried out four independent iterations on 70% of the corpus before reaching a saturation point. We reached a substantial agreement $d = 0.777, p = .000$.

Perceived as	Condition	
	Prosocial	Coercive
Prosocial	19	3
Coercive	5	18
I do not know	0	7

Table 32: Results (counts) from the coding of the question: 'Why did Push-one did what it did with the puzzle piece?'

The results show (see Table 32) that the children identified the reason to intervene of the robot correctly and there was a significant association between the coding of the answers of the children and the conditions. ($\chi^2 = 17.33, d = 2, p = < .000, \phi = .547, p = < .000$). Overall, we considered the manipulation of the robothing's strategy successful.

Figure 71: The strategy of the robothing (prosocial or coercive) and the action of the child (taking or not taking the last available piece) on the perceived helpfulness of the robot compared pre- and post- measurements

8.5 RESULTS

In this section, we report the results of Study 6. The results are reported per measure and are linked to the corresponding hypothesis. To reiterate, the hypotheses were as follows:

- **H1.** The prosocial strategy will increase children's —a) post-interaction perception of helpfulness of the robothing of the robothing b) the perception of collaboration with the robothing —more than a coercive strategy for conflict resolution;
- **H2.** The prosocial intervention will increase children's —a) post-interaction perception of helpfulness of the other child in respect b) the perception of collaboration with the other child —more than a coercive strategy for conflict resolution.
- **H3.** The prosocial strategy will increase children's prosocial behaviors towards the a) other child and b) the robothing after the intervention more than a coercive strategy for conflict resolution.

8.5.1 Perception of Helpfulness of the Robothing (H1a)

For perception of helpfulness of the robot, we were interested in whether this is affected by the condition (i.e., prosocial and coercive strategy) but also, as reported in the data analysis section, we were interested in whether this is affected by the action of the child in the game (taking the last piece or not

Figure 72: The simple main effect of the strategy of the robothing (prosocial or coercive) on the perceived helpfulness of the robot compared pre- and post-measurements

taking the last piece). To this end, we conducted a three-way mixed ANOVA with the condition, the action of the child, and pre- and post-measurements of the perception of helpfulness of the robot. There was no statistically significant three-way interaction between the strategy of the robot (prosocial vs. coercive) and the action of the child (taking the last piece vs. not taking) on the helpfulness of the robot compared pre- to post-measurements, $F(1, 54) = 2.635$, $p = .110$, partial $\eta^2 = .047$, (see Figure 71).

Considering there was no significant three-way interaction, we looked at whether there were any significant two-way interactions. There was a statistically significant two-way interaction between the strategy of the robothing and the perceived helpfulness of the robothing pre- and post-measurement, $F(1, 54) = 11.087$, $p = .002$, partial $\eta^2 = .170$ (see Figure 71). The other two two-way interactions were not statistically significant ($p > .05$). To investigate where the significant effects in the two-way interaction lay, we looked at the simple main effects.

We found a statistically significant simple main effect of pre- and post-measurement at the prosocial condition level, $F(1, 54) = 28.772$, $p < .001$, partial $\eta^2 = .348$ but not at the coercive condition level, $F(1, 54) = 0.399$, $p = .531$, partial $\eta^2 = .007$. And, there was a statistically significant simple main effect of condition at the post level, $F(1, 54) = 32.745$, $p < .001$, partial $\eta^2 = .313$ but not at the pre-measurement level, $F(1, 54) = 1.001$, $p = .322$, partial $\eta^2 = .018$ (see Figure 72). As hypothesized (**H1a** *The prosocial strategy will increase children's a) post-interaction perception of helpfulness of the robothing*), participants perceived the robothing more helpful in the prosocial condition than in the coercive condition (mean difference of 1.539

Figure 73: The strategy of the robothing (prosocial or coercive) and the action of the child (taking or not taking the last available piece) on the perceived helpfulness of the other child compared pre- and post- measurements

Figure 74: The simple main effect of the strategy of the robothing (prosocial or coercive) on the perceived helpfulness of the other child compared pre- and post-measurements

(95%CI,0.916to2.162)), and more helpful in the prosocial condition after the interaction with the robothing than before (a mean difference of 1.493 (95%CI,0.935to2.051)).

Figure 75: The simple main effect of the action of the child during conflict elicitation (taking the last piece or not taking the last piece) on the perceived helpfulness of the other child compared pre- and post-measurements

8.5.2 Perception of Helpfulness of the other Child (H2a)

For perception of helpfulness of the other child, we were interested in whether this is affected by the condition (i.e., prosocial and coercive strategy) but also, as reported in the data analysis section, we were interested in whether this is affected by the action of the child in the game (taking the last piece or not taking the last piece). To this end, we conducted a three-way mixed ANOVA with the condition, the action of the child, and pre- and post-measurements of the perception of helpfulness of the other child. There was no statistically significant three-way interaction between the strategy of the robothing (prosocial vs. coercive) and the action of the child (taking the last piece vs. not taking the last piece) on the helpfulness of the other child compared pre- to post-measurement, $F(1,54) = 1.015$, $p = .318$, partial $\eta^2 = .018$ (see Figure 73).

We then looked at the two-ways interactions. There was a statistically significant two-way interaction between the strategy of the robothing and the perceived helpfulness of the other child pre- and post-measurement, $F(1,54) = 5.314$, $p = .025$, partial $\eta^2 = .090$ (see Figure 74). There was also a statistically significant two-way interaction between the action of the child and the perceived helpfulness of the other child pre- and post-measurements, $F(1,54) = 4.438$, $p = .040$, partial $\eta^2 = .076$ (see Figure 75). The other two-way interaction was not statistically significant ($p > .05$).

To see where the significant effects in the two-way interactions are, we looked at the simple main effects. For the two-way interaction of strategy of the robothing and the perceived helpfulness of the other child pre- and

post-measurement, there was a statistically significant simple main effect of condition at the post-measurement level, $F(1, 54) = 18.431$, $p = .002$, partial $\eta^2 = .161$, but not at the pre-measurement level, $F(1, 54) = 0.779$, $p = .421$, partial $\eta^2 = .012$. Participants perceived the other child more helpful in the prosocial condition than in the coercive condition after the game (post measurement level) (mean difference of 1.155 (95%CI, 0.435 to 1.874)). There was a statistically significant simple main effect of pre- and post-measurement at the coercive condition level, $F(1, 54) = 6.473$, $p < .014$, partial $\eta^2 = .107$, but not at the prosocial condition level, $F(1, 54) = 0.502$, $p = .482$, partial $\eta^2 = .009$. The mean helpfulness score in the coercive condition level was lower in the post condition than in the pre-measurement condition, a mean difference of -0.719 (95%CI, -1.285 to -0.152). In other words, participants perceived the other child significantly less helpful in the coercive condition at the end of the game (post-measurement) compared to at the start of the game (pre-measurement). As hypothesized (H2a), the prosocial strategy increased children's post-interaction perception of helpfulness of the other child in respect of the pre-interaction perception of the other child more than a coercive strategy.

For the two-way interaction between the action of the child and the perceived helpfulness of the other child pre-measurement and post-measurement, there were no simple main effects statistically significant for the action of child at either the pre-measurement level or the post-measurement level ($p > .05$). There was a statistically significant simple main effect of pre- and post-measurement at not taking the last piece level, $F(1, 54) = 7.323$, $p = .009$, partial $\eta^2 = .119$ but not at the taking last piece level, $F(1, 54) = 0.265$, $p = .609$, partial $\eta^2 = .005$. The mean helpfulness score in the not taking the last piece level was lower in the post-measurement condition than in the pre-measurement condition, a mean difference of -0.679 (95%CI, -1.183 to -0.176). In other words, participants who did not take the last piece of puzzle perceived the other child, who did take it, as less helpful at the end of the game (post-measurement) compared to at the start of the game (pre-measurement).

8.5.3 *Perceived Collaboration with the Robothing (H1b)*

For perceived collaboration with the robothing, we were interested in whether this is affected by the condition (i.e., prosocial or coercive strategy) but also, as reported in the data analysis section, we were interested in whether this is affected by the action of the child in the game (taking the last piece or not taking the last piece). To this end, we conducted a two-way mixed ANOVA with the condition, the action of the child, and the perceived collaboration with the robothing. There was no statistically significant interaction between the strategy of the robothing (prosocial or coercive) and the action of the child (taking or not taking the piece) on the perceived collaboration with the robothing, $F(1, 54) = 1.777$, $p = .188$,

partial $\eta^2 = .032$. There was a statistically significant main effect between the strategy of the robothing (prosocial vs. coercive) on the perceived collaboration with the robot, $F(1, 54) = 43.978$, $p < .001$, partial $\eta^2 = .503$. The mean of perceived collaboration with the robothing score was higher in the prosocial condition than in the coercive condition, a mean difference of 1.784 (95%CI, 2.267 to 1.300). In other words, the participants perceived to have collaborated more with the robothing, when the robothing exhibited a prosocial strategy. As hypothesized (H1b), the prosocial strategy increased children's perception of collaboration with the robothing after the intervention more than a coercive strategy.

8.5.4 *Perceived Collaboration with the other Child (H2b)*

For perceived collaboration with the other child, we were interested in whether this is affected by the condition (i.e., prosocial vs. coercive strategy) but also, as reported in the data analysis section, we were interested in whether this is affected by the action of the child in the game (taking the last piece or not taking the last piece). To this end, we conducted a two-way mixed ANOVA with the condition, the action of the child, and the perceived collaboration with the other child. There was no statistically significant interaction between between the strategy of the robothing (prosocial or coercive) and the action of the child (taking or not taking the last piece) on the perceived collaboration with the other child, $F(1, 54) = 0.585$, $p = .448$, partial $\eta^2 = .011$). There was a statistically significant main effect between the strategy of the robothing (prosocial or coercive) on the perceived collaboration with the other child, $F(1, 54) = 6.164$, $p = .004$, partial $\eta^2 = .147$. The mean perceived collaboration with the other child score was higher in the prosocial condition than in the coercive condition, a mean difference of 0.668 (95%CI, 0.228 to 1.107). Children perceived to have collaborate more with the other child when the robothing exhibited a prosocial strategy. As hypothesized (H2b), the prosocial intervention increased children's prosocial behaviors towards the robothing after the intervention more than a coercive intervention.

8.5.5 *Behavioral Observation: Prosocial Behaviors after the Intervention (H3a)*

For perceived collaboration with the other child, we were mainly interested in whether this is affected by the condition (i.e., prosocial vs. coercive strategy, see Table 33). We found a statistically significance association between the prosocial behavior of the children after the intervention (coded) and the experimental conditions (prosocial vs. coercive strategy). ($\chi^2 = 11.745$, $d = 1$, $p = < .001$, $\phi = .450$, $p = < .001$). We use the values of the standardized residuals to interpret the Chi-Square results. There are significantly less instance of behaviors coded none (so not prosocial) in the

prosocial condition ($z=-1.7$) than the coercive condition ($z= 1.7$). Conversely, there are significantly less instance of behaviors coded prosocial ($z=-1.8$) in the coercive condition than in the prosocial condition ($z= 1.7$). In other words, participants were significantly less prosocial between each other in the coercive condition. Therefore our hypothesis (H3a The prosocial intervention will increase children’s prosocial behaviors towards the other child) is supported.

	Prosocial	Coercive
Prosocial	21	9
st. residuals	1.7	-1.8
None	9	21
st. residuals	1.7	1.7

Table 33: The results of the annotation of prosocial behaviors (prosocial or none) per experimental condition after the game. Data are counts and standardized residuals (i.e., residuals). Standardized residuals in bold indicate significance.

To have a granular understanding of how the actions of children in the game impact the prosocial behaviors of children, as reported in the data analysis section, we were interested in whether this is affected by the action of the child in the game (taking the last piece or not taking the last piece). We found a statistically significance association between the prosocial behavior of the children after the intervention (coded) and the actions of the children (taking the last piece or not taking the last piece). ($\chi^2 = 12.381$, $d = 3$, $p = .006$, $\phi = .462$, $p = < .006$). We use the values of the standardized residuals to interpret the Chi-Square results. There are significantly more instance of prosocial behaviors (coded prosocial) in the prosocial condition when the child did not take the last piece ($z=-3.8$) than the coercive condition ($z= -3.8$). Conversely, there are significantly less instance of behaviors coded prosocial ($z=-1.7$) in the coercive condition when the child did not take the last piece.

8.5.6 Help test (H3b)

The results of the help test are reported in Table 34. We did not find any statistical significance between conditions (prosocial vs. coercive). Therefore our hypothesis (H3 The prosocial intervention will increase children’s prosocial behaviors towards the **b**) the roboting after the intervention more than a coercive intervention) is not supported.

	Prosocial	Coercive
Helped	19 (63%)	14 (50%)
Did not help	11 (37%)	14 (50%)

Table 34: The number of children that helped the robot at the end of the experiment divided over the conditions. Data are counts.

8.5.7 Share test (H_{3a} , H_{3b})

The results of the share test are reported in Table 35. We did neither find any statistically significant difference between conditions (prosocial vs. coercive) nor any statistically significant difference between the actions of the child in the game (taking the last piece vs. not taking the last piece). Therefore our hypotheses (H_3 The prosocial intervention will increase children's prosocial behaviors towards the **a)** other child and **b)** the robothing after the intervention more than a coercive intervention) are not supported.

Number given	Child		Robothing		Self	
	Giving	Taking	Giving	Taking	Giving	Taking
0	1	5	1	7	1	0
1	5	6	1	5	2	1
2	21	11	26	14	21	8
3	2	6	2	2	5	8
4	0	0	0	0	1	10
5	0	0	0	0	0	0
6	1	0	0	0	0	1

Table 35: The number of stickers, 6 had to be distributed, children allocated to the robot, the other child, or themselves after the experiment.

8.5.8 Discussion

In this study, we investigated how a robothing strategy (prosocial vs. coercive) to intervene in conflict about resources in a game influences children's prosocial behaviors and the perception of helpfulness and collaboration with the robothing and children. In this section, we critically discuss the results of the study. Then, we reflect on the findings and limitations of the study.

Overview of the Results and Implications for cHRI

A prosocial strategy of a robothing to intervene in a conflict in play positively impacts children's perception of helpfulness and collaboration. Children appear to be sensitive to prosocial interventions of a robothing, and we have found indications that children's perceptions of a robothing are impacted by the type of strategy the robothing use in the conflict, which is in line with the literature in HRI with adults [63]. As expected, we have found that a robothing that intervenes in a conflict with a prosocial strategy (i.e., giving an object children do need) is perceived as more helpful after the game. Children perceived themselves to have been collaborating more with the robothing when the robothing intervened with a prosocial strategy. The prosocial strategy of a robothing impacts how helpful children perceived the other child to be too, again in line with the literature [63]. Moreover,

children perceived to have collaborated more with the other child when the robothing exhibited the prosocial strategy. Our results are in line with the developmental psychology research [91, 248, 284] on the matter that shows how children tend to see more helpful and collaborative with somebody that employ a prosocial strategy as opposed to a coercive strategy. Interestingly, the coercive strategy is considered less helpful and less collaborative than our previous work. In fact, in Study 5 (Chapter 7) we have investigated the very same action underling a prosocial strategy (i.e., taking away an object after a conflict about resources in the game) and observed that – despite being less helpful than a prosocial action such as giving)– a coercive strategy was seen as a helpful action to stop the conflict. A possible explanation is that when children directly experience the robothing’s coercive behavior, they might have stronger reactions than when they see it in VHRI. More comparative studies are needed to understand how well VRI findings replicate during in-person studies.

At the behavioral level, we found an effect of the robothing’s intervention. Children helped, shared, and informed each other more when a robothing acted prosocially. Therefore, there is an indication that a prosocial strategy of a robothing might compel children to be more prosocial in the game, an effect in line with the social psychology literature about children and prosocial behaviors [97]. Another explanation is that children felt the need to reciprocate the prosocial behaviors of the robothing indirectly. We show that the children who did not take the last piece of puzzle available are the ones that were more prosocial after the game when a robothing intervened with a prosocial strategy and less prosocial when the robothing intervened with a coercive strategy. The child who did not take the last piece was left with no pieces to continue and complete the puzzle. The only way for the child to finish would have been to ask the other child to share objects. We speculate that the child who did not take the last piece might have felt the intervention of the robothing strongly as if the robothing’s act was perceived as directed to him/her. As a result, the child who did not take the last piece might have been subject to indirect reciprocity [264] (similarly to what happened in Study 4 Chapter 4). This effect might also be supported by the fact that the children who did not take the last piece were less prosocial when the robothing showed a coercive strategy.

Another crucial aspect that had an essential role in our results are children’s actions *after* the conflict was elicited, before the robot’s intervention. Children appeared to respond either by taking the last piece of the puzzle for themselves or not taking any action. We found that a child’s actions impact children’s perception of helpfulness and collaboration with the other child in the game. Children who did not take the last piece of the puzzle perceived the other child, the one who did take it, as less helpful at the end of the game. Moreover, children perceived to have collaborated less with the child who did take the last piece. This insight is relevant to the literature on robots in groups; we need to consider the effects of a robot’s

intervention and the ripple effect (at the emotional and behavioral level) of this intervention and the task [353]. Research in HRI has shown that a robot's behavior causes a ripple effect in a team, but our results show that we need to factor in the behaviors of the other humans in the group. It is especially salient when studying HRI and cHRI in-the-wild [185].

While the behavioral results show that a prosocial behavior of a robothing positively impacts children's prosocial behaviors, we should be cautious not to over-interpret these results. We only coded the presence or absence of children's prosocial behaviors after the robothing intervention. We did not qualify or quantify those behaviors as it was beyond the study's scope. Moreover, we did not analyze the content of children's conversations. We anticipate that analyzing the children's non-verbal and verbal behaviors after a robothing intervention will give a set of granular insights on the behavioral effects of a robothing intervention, but we leave this analysis to future work. At the same time, we feel that our findings shed light on an under-explored but relevant facet of cHRI by providing a relevant first indication of the behavioral effect of playing with a robothing that intervenes in children's conflict in collaborative play. More attention is needed to understand how to design the intervention of a robothing in group interactions [184]. We leave the in-depth analysis of children's behaviors and explore the design space of cHRI in highly dynamic interactions to future work.

Lastly, behavioral results show that a robothing intervention in a conflict appears not to impact the way children share the reward of a game or help the robothing after a game. Our forced behavioral measures, share-test and help-test, show that children share the reward of a game with each other and help the robothing irrespective of the robothing's intervention. The share-test result shows that children distributed the game's rewards equally among the players, with no effect of either robothing's or other child's behavior. While we did not expect these findings, there is a line of research that explains how children tend to divide rewards equally among players and to enforce the sharing norm, unless a child deviates strongly from this norm [340]. Therefore, we can contemplate that children might have acted to enforce a norm and that a robothing or another child's actions do not represent a substantial deviation from the tacit norm of equal sharing. Another possible explanation is that the instrument (although profusely used in related work [340, 300]) could not capture the tendency to share after the game well enough. However, our pilot test ensured a degree of validity for it. We leave the exploration of more potent instruments to evaluate children's sharing behaviors to future work. The help-test showed a similar result. No matter the behavior of the robothing in the game, children tended to help the robothing in need. While this result goes against our expectations and our previous work (Study 4 Chapter 4), we infer that children acted to support the robothing in an instrumental need only. Research in developmental psychology shows that children are compelled to respond to the instrumental of an agent [370], due to their general tendency to be sympathetic. While

this tendency tends to diminish in middle childhood and be more present in early childhood, one explanation of our results could be that children acted more with a sympathy motive than to reciprocate the behavior the robothing has exhibited in the game. Another possible explanation is that children might have felt the urge to behave “nicely” because they were in front of the facilitator during the help-test. Suggestivity and need to please adults might have played a role, and it is a known factor when carrying out studies with children [243].

Limitations

Our study has some limitations. First, there could have been a limitation on internal validity. We have set the study in a familiar place for the children, but it is not easy to have complete control over a space outside a laboratory and make sure to make WoZ conditions consistent. While our protocol and WoZ training assured a relatively high degree of consistency, we are aware that factors like temperature, lights, or floor traction might have created minimal variation in the speed and trajectory of the robothing. Another challenge is to evaluate the perception and behavior of children. We have chosen measures attuned to children, and we have chosen not to overwhelm children with too many questions in the survey. In so doing, we have followed best practices to carry out experiments with children [243]. However, the lack of standardized measures to understand children’s perception of a robot and validated behavioral protocol makes it hard to find valid measures. Overall, we think that by following best practices and building-upon previous work as much as possible, we have guaranteed a reasonable face validity of our measures. Nonetheless, we interpret our results cautiously, as explained in our discussion.

Lastly, the complexity of running studies with children in ecologically valid settings is very high. We needed to create an ad-hoc protocol for the setting and control many potentially fuzzy variables with our game design. As a result, one can raise a concern about how well our protocol represents naturally occurring playing behaviors. We could not afford to let the game unfold for experimental reasons, and the robothing is participating in the full game. The game turns needed to be forced with the game mechanics, and the robothing behaviors minimized to the prosocial and coercive interactions. While we believe that this study has given realistic insights about the potential dynamics between robothings and children, future work must study more in-the-wild and uncontrolled situations, as suggested by Hinds and Jung [185]. Studies should better deal with children’s fuzziness and uncertainties in play to delineate more robust theories in cHRI. To the best of our knowledge, ours was one of the first attempts to study a mobile robot interacting with children. Most of the robots for children cannot afford such complex interaction dynamics and ever-changing situations. While aware of the limitations in ecological validity, we think that our protocol approxi-

mated reasonably a real-life game situation and gave relevant insights for future work.

8.5.9 Study 6: Conclusions

In study 6, we have provided first indications that a robothing strategy to intervene in a children's conflict has an impact both at perception and behavior level. A prosocial strategy, operationalized as a giving action with sine-wave motion-style, positively impacts children's perception of helpfulness of and collaboration with a robothing and a child and on prosocial behavior in the game after the intervention. We find that children perceive a robothing and the other child in the game as more helpful and collaborative when the robothing intervenes in a conflict with a prosocial strategy. Children share and help each other more after the robothing has exhibited a prosocial behavior. To the best of our knowledge, this is the first account in the cHRI literature of the positive effects of low/non-anthropomorphic robots that interact non-verbally in cHRI.

8.6 CHAPTER CONCLUSIONS

Chapter 8 has presented the last study of the dissertation, Study 6. In the chapter, we have honed-in on the effects of a robothing on children's prosocial behaviors, collaboration, and perceptions. In so doing, the chapter contributes to the fourth *RQ4. How do children interpret and perceive the non-verbal behavior of low/non-anthropomorphic robots in play?* and sixth research question of the dissertation *RQ6. What are the effects of a robothing behavior on the prosocial behavior and collaboration of children in play?*

Understanding how children are impacted by interacting with a robothing is crucial for the scope of the dissertation. Simultaneously, the study presented in the chapter was one of the most difficult to carry out due to the exponential complexity to design effective experimental protocols in-the-wild with multiple children, even if only in a WoZ paradigm. Also, carrying out studies outside the laboratory is laborious and time-consuming; we have taken more than three months to gather just enough data to carry out the analysis.

Despite the challenges, the findings show that a robothing interacting with a prosocial strategy, operationalized as a giving behavior, have positive effects on children's prosocial behaviors and positively impact the perception of helpfulness collaboration of the children. Therefore, corroborate the overarching thesis that a low/non-anthropomorphic robot could impact children's prosocial and collaborative dynamics only with simple non-verbal behaviors. At the same time, we show exciting dynamics between the children after the intervention of the robothing, which is valuable to explore further to design more sophisticated interactions with robothings. A de-

signer of cHRI could use and implement further our protocol to see whether the findings replicate in other situations or cultures. At the same time, we anticipate that more qualitative approaches might yield more productive results or afford long-term interactions, which we did not experimentally study.

Although the findings are promising, we interpret them very cautiously due to the possible issues with internal and face validity. Moreover, there are many variables at play in multi-party interaction that we did not account for. While we take our results with caution, we feel that they contribute to our understanding of the scope of robotthings in this dissertation and open-up avenues for cHRI research to build upon our findings and enable more research on playful interventions to support children's collaboration in collaborative play.

DISCUSSION AND CONCLUSION

“A brilliant solution to the wrong problem can be worse than no solution at all: solve the correct problem.”

Donald A. Norman (1989)^a

^a I suggest to listen to the songs **Lune and Rouge** by Tokimonsta while reading this chapter

“Oh, looks like Lucas and Anna are quiet.” - thinks Dad while folding the laundry
“They were so fierce with that puzzle and now...” - wonders Dad while walking away from the laundry room.

“Hey Arianna, what happened to the kids, I can barely hear them now.” - says Dad while walking into the home office of Anna’s and Lucas’ mom.

“Not sure, I was working on my essay, but I bet it’s that new toy.” - suggests Mom looking up from her screen.

“Mmm, oh yeah? Which one?” - asks Dad confused.

“It’s the robot toy we bought for Anna’s birthday. It is a new toy. Apparently, it is developed to collaborate with kids when they play with puzzles. It displays simple prosocial behaviors here and there to stimulate collaboration. I didn’t think it could work, to be honest.” - explains Mom.

“Does it speak to the kids? Does it teach’em how to collaborate?” - asks Dad perplexed.

“No, it hears there is an argument between the kids and shares objects with them or takes objects away, it’s simple. It lets them figure it out by themselves how to respond in a prosocial way, apparently.” - respond Mom.

“Mmm, and just moving around pushing stuff is enough? Sounds too good to be true.” - comments Dad skeptically.

Mom and Dad approach the room of Anna and Lucas. Standing by the door, they observe the children playing together and having fun with the puzzle
“Mmm, ok it might work, but I’d like to learn more about this.” whispers Dad.¹

In this dissertation, we have explored the design space of toys – as featured in the fictional story above – endowed with social robotic technology to support children’s collaboration in play. In various studies, we have investigated the design of robotothings, low/non-anthropomorphic robots that communicate their prosocial intentions to influence people’s behaviors, leveraging their nonverbal communication affordances. With chapter 9,

¹ This is a fictional story inspired by true events. The story is inspired by the chats I had with parents of children participating in the research. Parents frequently asked about the educational implications of interacting with a robotothing in play.

we conclude the dissertation and – like the Dad in the story above – we question what we have learned and the impact of the research. We provide an overview of the findings, and we review the theoretical, methodological, and design implications. We critically assess the research limitations and discuss how the research lays the groundwork for future work. Finally, we reason about the impact of the research, offering an overview of the contributions.

9.1 OVERVIEW OF THE FINDINGS

The dissertation explored how social robotic technology could promote collaboration among children. We stepped outside the child-robot interaction status-quo, considering playful interventions that non-verbally stimulate children to behave prosocially and collaborate when playing together instead of focusing on humanoid robots that verbally tutor or mediate the interaction of children. To this end, we have probed the design space of what we defined as *robothings*. The term ‘robo’ stands for robots, automated artificial agents, and the term *things* borrowed by Bruno Latour to indicate everyday objects with agency and shape our reality in our everyday practices. *Robothings* are low/non-anthropomorphic robots, robots that are hybrids between a toy and a social robot. They communicate their prosocial intentions to influence people’s behaviors, leveraging their nonverbal communication affordances. While influencing a person’s behavior, they leave the interaction to humans and room for individual reflection about prosocial behaviors. We explored how to operationalize playful interactions with a *robothing* and design nonverbal behavior for a *robothing* to intervene in children’s collaboration. In Chapter 1 we posed two aims:

- AIM 1: To investigate how robots that have less human-like form and behaviors can promote children’s (7-11 years old) collaboration through play; and
- AIM 2: To probe the design space of non-anthropomorphic nonverbal social communication in child-robot interaction.

In this section, we return to these two aims by answering the research questions posed at the beginning of the research, as listed in Chapter 1, the Introduction. We provide an overview of the main findings, and we briefly discuss them per research question. Lastly, we return to the two aims we set to accomplish with the research and details of how we have fulfilled them. We conclude the section with an overview of the ‘ABCs’ of *robothings* and the lessons learned.

9.1.1 *RQ1. How do children regulate prosocial behaviors to collaborate in play?*

Our first question is related to how children regulate prosocial behaviors to collaborate in play. Based on the literature, our premises were that prosocial and reciprocal dynamics, through actively promoting collaboration, positively impact the way children collaborate. Chapter 2 showed that the main issues in collaboration are lack of prosocial behaviors and lack of strategies to resort to prosocial behaviors in conflicts or poor collaboration. Therefore, promoting interpersonal prosocial dynamics, such as helping and sharing and supporting conflict resolution, is critical to support collaboration. In particular, promoting prosocial behavior among peers is essential. Theory in Chapter 2 showed that when a child exhibits a prosocial action towards another child, the prosocial action motivates the child who receives it to reciprocate and collaborate. However, theory lacked behavioral details about the actions children take to regulate prosocial behaviors in play.

*Discussion Findings
Study*

To have a granular understanding of how children's actions unfold to regulate prosocial behavior and collaborate in play, we have carried out an analog observation of children in collaborative play activities (Study 1, Chapter 3). Understanding how children's actions unfold to regulate prosocial behaviors was a prerequisite to understanding how and when a robot should intervene in children's collaboration. The findings from the systematic observations of children's behaviors contribute to the answer to our research question. Nonverbal behaviors are essential to regulate prosocial behaviors to collaborate in play. We have shown that the regulation of prosocial behaviors among children appears to happen between —what the literature calls —'bid' sequences of prosocial and conflict actions. Children showed three primary responses to a sharing or conflicting offer. Either turning towards each other (i.e., accepting the offer) or turning against each other (i.e., responding with aggression) or turning away from each other (i.e., not accepting the offer and ignoring the bid). Lastly, we showed that children tend to form sub-groups instead of playing with all the group members. On many occasions, children tend to dominate or exclude other children from the prosocial dynamics and collaboration in play.

Reflections

Our findings mainly focused on the nonverbal behaviors of children. We showed that children's nonverbal actions and how actions are sequenced play a significant role in regulating children's prosocial behaviors. While our findings are supported by literature [284], we did not explore other nonverbal cues, such as speech, or nonverbal cues that might also play a role. The tasks we asked the children to perform (i.e., 3D construction puzzles) during our observations might have made children's nonverbal behaviors more relevant than they usually are by being a task around objects. Nevertheless, we believe that our findings represent how children *actually* regulate prosocial behavior to collaborate in games with objects, as the literature confirms this insight.

9.1.2 RQ2. How Should the Interaction with a Robothing be Designed to Impact Prosocial Dynamics in Play?

We sought to understand how a robothing can interact with children to impact prosocial dynamics, thereby promoting collaboration in play. Designing the interaction with a robothing is challenging as there is practically no HRI and CHRI literature available. To answer our research question, we made sense of and synthesized a large and body of literature from other disciplines (reviewed in Chapter 2), as well as the findings from the observations of children behaviors in context (Chapter 3). The result of this effort is a conceptual framework (Chapter 2) (visualized in Figure 76, re-proposed from Chapter 2). We operationalized the conceptual framework (Chapter 4 and Chapter 6) to easily translate complex theories and complex socio-emotional dynamics of children in interaction scenarios and robothing interventions (re-proposed from Chapter 4).

Conceptual Framework

To summarize, the conceptual framework posited that a robothing should partake in object-oriented games with small groups of children. By partaking in the games, a robothing should intervene with prosocial actions to offer help to children. Thus, we explore a playful intervention to support children's collaboration in play with social robotic technology. At the **intervention level**, our goal is to promote the social level of collaboration, trying to act on children's motivation to be prosocial to one another in collaborative play. The robot aims to influence children to collaborate and be prosocial through participating in play: by showing prosocial behaviors, the robot tries to influence children's behaviors. When we interact with somebody that helps us, we are compelled to help in return [264]. When we work in a team, we tend to collaborate more with each other when teammates share resources and information with us [249]. Children experience a similar effect when playing together [284]. Research shows that mere exposure to the action of helping or sharing of one child in play leads to reciprocity and a greater tendency to be prosocial in the short and long term [101]. Actions such as helping, sharing, and informing establish the prosocial norm and prompt reciprocal dynamics in a group [96]. Prosocial and reciprocal dynamics promote collaboration, even when collaboration is challenging [248].

The robothing shares objects in play (Chapter 4) or intervenes in conflicts (Chapter 6). Robothings' prosocial actions and robothings' actions that underpin a conflict resolution strategy should be sufficient to motivate children to reciprocate more in the game or share and collaborate instead of arguing. The findings of in-person studies (Study 3, 4 (Chapter 4 and Study 6 (Chapter 8) corroborate our interaction design. Robothings' prosocial actions and robothings' conflict resolution actions motivate children to be prosocial.

Reflections

Although we showed that our interaction design is relevant, we know that our interaction design could simplify a very complex social phenomenon.

Figure 76: The figure is visualizing the conceptual framework that guide the dissertation. The visualization shows the intervention level with the high level interaction and the communication level with the communication.

The prosocial dynamics unfolding in play can be far more intricate than in our interaction scenarios. The findings from our in-person studies showed that child-robot interactions in play are more sophisticated than we have envisioned. Study 4 (Chapter 4) show that while children sanctioned the robothing by excluding it from the game because it stopped to share after two game sessions, they still kept collaborating among themselves. At the same time, children did not perceive the robot's behavior as hindering as we anticipated. In Study 6 (Chapter 8), children perceived a sharing action to resolve a conflict as more helpful and collaborative than a coercive action. Nevertheless, children helped the robothing in need after the experiment, no matter what conflict resolution behavior is exhibited. While we did check for the potential effect of personal differences and relational dynamics, in our interaction design, we do not model group dynamics, which might have played a role in 'child-robothing-interaction'.

Nonetheless, the conceptual framework and guidelines supported us in understanding how to design the interaction between children and a robothing to impact children's prosocial dynamics in play. Thanks to our conceptual framework, we have translated a complex social scenario into a comprehensible interaction scenario with a straightforward interaction flow that supported us in designing and evaluating cHRI. We anticipate that designers could use our conceptual framework in cHRI further to explore the effects of robot prosociality on collaboration.

9.1.3 *RQ3. How Should the Non-verbal Behavior of Low/non-anthropomorphic Robots Be Designed to Communicate a Robot's Intention to Children?*

Crucially, a robothing must communicate its intention to children. At the intervention level, we have identified actions such as helping, sharing, or hindering to intervene in the collaborative and prosocial dynamics of play. These prosocial behaviors needed to be further specified. To this end, we sought to break down the dynamics of the communication of robothings in 'human terms' and identify key nonverbal behaviors to communicate the prosocial intentions of a robothing or lack thereof. We posited that by leveraging nonverbal communication in 'human terms', a robothing could mitigate the adverse effects humanoid robots might have in cHRI by relying only on low/non-anthropomorphic cues and behaviors. However, this was a challenging task due to the lack of broader design guidelines in HRI and the complexity of prosocial communication. Surveying the HRI and human-communication literature (Chapter 2), we have integrated our conceptual framework with seven design principles (Chapter 4) for the nonverbal behavior of low/non-anthropomorphic robots that answer our research question.

To summarize, the principles are (i) **Shared Space**: to communicate its intention a low/non-anthropomorphic robot should interact in a shared space in front of the children; (ii) **Grounding communication**: The space, the people, and the objects in the space should be clear, the robot should not refer to people, objects or spaces that are not in the shared space; (iii) **Grounding subject** A low/non-anthropomorphic robot should clarify the recipient of its communication by aiming at the recipient with the movement it affords; (iv) **Grounding objects**: a low/non-anthropomorphic robot should clarify the object of its communication aiming at the object with the movement it affords; (v) **Action=social communication**: The actions of a low/non-anthropomorphic robot should embody the goal of the communication, with no need for a motion-style; (vi) **Primary actions** a low/non-anthropomorphic robot should use actions such as giving, walking, pointing, and nudging because the intention of these actions is obvious to humans: they are sort of primary actions that encapsulate intentionality; and (vii) **Legibility**: an interactant should be able to explain the reason of a low/non-anthropomorphic robot behavior only by experiencing/watching the behavior.

Findings

Our empirical studies provide numerous insights into how well the design principles enable robothings to communicate children's intentions. Study 2 (Chapter 4) showed that a simple rotation of the base of a robothing is enough to communicate social attention to a child and the intention to refer to an object. Simple rotations towards a person or an object are cues to the helpful intention of the robot too. Study 3 (Chapter 4) showed that adding nonverbal sounds to a robothing's motion does not reinforce child-robot communication; robothing's actions alone can communicate help-giving

intention with locomotion. Actions of giving and taking objects are clear to children who interpret them as helpful (Chapter 4) or collaborative (Chapter 8) depending on the interaction situation.

Simultaneously, the lessons learned from our studies highlighted the need for the principles to be updated. Thanks to our co-design workshops with children, we understood that the motion-style of a robothing might not be as unimportant to communicate intention as we had posited. As a result, we revised one design principle to include the possibility of motion styles (i.e., sine-wave, jerky, and linear) to overlay actions, thereby reinforcing or modifying the communicative meaning (Chapter 6, Chapter 7). Nevertheless, in Study 5 (Chapter 7), we found a smaller role for the motion-style when evaluating the interplay of motion styles and actions. Actions appear to play a more significant role in communicating a robothing's intention. Only one style (i.e., sine-wave) appeared to interplay with the action of a robothing to positively modify its communication (i.e., the action is perceived more prosocial with a sine-wave motion style). While our findings were in line with the literature related to locomotion styles [207], we could not provide a definitive answer regarding this aspect of nonverbal behavior design.

Lesson Learnt

Reflecting on the way to design nonverbal behavior of low/non-anthropomorphic robots, we have gone a step further in current research on designing robot communication in 'human terms'. While, as we have seen in Chapter 2, other HRI researchers actively distinguish between pragmatic (i.e., goal-directed actions) and expressive (i.e., communication of intention traits and aspects of nonverbal motion) motion [151], we did not. We have shown that robothings' actions that might at first glance appear merely functional (or pragmatic as per [151]), such as the locomotion of a robothing pushing an object, is interpreted as a helpful prosocial action (or expressive as per [151]) in the unfolding interaction. Motion-styles impact building a 'character' of robothing, but our findings—even if limited—suggest that distinguishing pragmatic and expressive motion for low/non-anthropomorphic motion might be superfluous.

We understood that the form and appearance of a robothing affect how we make sense of behavior through Push-one's design. Therefore, we elaborate **two additional design principles** which we take into account to design **the form** of a robothing, that is, the surface appearance and embodiment of a robothing. The form of a robothing to not cause a mismatch between its function (what it does), its communication (what it wants to achieve by interacting), and what a child may infer from the robot's appearance. There should be a balance between a realistic non-anthropomorphic form (i.e., a form that is familiar because similar to already existing objects, for instance, a toy) that can ease children's understanding of the function of a robothing with an embodiment that is coherent with the behavior of a robothing. Thus our other principles are: (viii) **Form/behavior/function adherence**: The form and the nonverbal behavior of a robothing should follow the imagined function of a robothing. We should maintain the correct

expectations about the robothing’s capabilities. Therefore the embodiment should not create false expectations of what the robothing can do or be endowed with physical, social cues beyond its function. Our perspective is to establish a developmentally and ethically appropriate *illusion of life* that could be beneficial to influence children’s prosocial behaviors; and, (ix) **Familiarity**: A robothing form should have a connect connection with realistic non-anthropomorphic form, even if abstract. The embodiment of a robothing should balance realism and familiarity with technical and aesthetic requirements. We strive to design interaction between the robothing and the children that, in the long run, might establish a thing/toy-like relationship between children and robothing.

Reflection

In line with our principles, we unveil a non-trivial aspect of ‘grounding’ [131] and parsing the meaning of a low/non-anthropomorphic behavior in the interaction that enables the social communication of robothings. Our behavioral studies show that *when* and *after which* action of the children a robothing intervenes has a high impact on the way the behavior is interpreted. Similar to Jung et al. [183], we can observe a parallel with the way humans ground language in conversations, taking into consideration the context in which an utterance is delivered to make sense of it and attribute the correct meaning. Therefore, the sequencing of actions in low/non-anthropomorphic robots’ nonverbal behavior appeared to become a sort of ‘*nonverbal syntax*’ and ‘*nonverbal semantic*’. It follows that the role of the scenario in which the nonverbal behavior of low/non-anthropomorphic robots interacts plays a significant role in sense-making. While our principles touched upon the disambiguation of aspects of the interaction scenario to ‘ground’ the interaction (i.e., ground the recipient, object, and intention of a robothing’s action), we did not actively design for nonverbal behavior sequencing. However, we have revealed a relevant feature for a low/non-anthropomorphic robot’s nonverbal communication, and our work enables more explorations in this direction.

We anticipate many other ways to design a low/non-anthropomorphic nonverbal behavior to communicate a robot’s intention to children beyond the principles we posited in the dissertation. We are aware that design researchers [299] are exploring various theories (e.g., Actor-Network Theory) and principles to enable non-anthropomorphic products to communicate intention. Moreover, while we have design Push-one according to all the ten resulting principles, we did not empirically test how a robothing’s appearance impacts its communication. Nevertheless, our design process provides insights to cHRI designers regarding the role of the form of a robothing and the importance of form/function/behavior adherence and familiarity. While our findings might apply only to the cHRI domain and in limited scenarios, we think that we have contributed to an evolutionary broadening of designing a low-non-anthropomorphic robot to communicate in ‘human terms’ to children.

9.1.4 RQ4. How Do Children Interpret and Perceive the Non-verbal Behavior of Low/non-anthropomorphic Robots in Play?

A fundamental aspect of the design of the nonverbal behaviors of robotthings is discerning how children interpret it and perceive it in context. A prerequisite to an effective interaction is a correct interpretation of the intended meaning of a behavior [240]. In this dissertation, we have focused on designing nonverbal communication for a robotthing that is non-conventional (like language is) and minimal. Therefore, children needed to understand the complex intention of a robotthing from simple non-conventional cues; all the communication needs to be parsed from the interaction. We evaluated how children read and attribute intention to (i.e., legibility) to a robotthing behavior and how children perceive the behavior of a robotthing in terms of traits and social qualities in play to answer our question.

Findings

We have found that a low/non-anthropomorphic robot's simple actions legibly communicate the robot's intention as we intended. Findings showed that a robotthing's minimal motion (i.e., social and deictic gaze-movements) (Study 2, Chapter 4) communicate social engagement and helpful referential information to children. Children could accurately understand the legibility of the minimal gaze-movements of the low-anthropomorphic robot, without human-like form or behaviors. Study 5 (Chapter 7) showed that a robotthing's actions (giving, taking, not intervening) legibly communicate to children the different intentions to intervene in a conflict only with locomotion. Study 6 (Chapter 8) provides further evidence of the communicative power of giving and taking actions of a robotthing in the interaction. Minimal-movements and a robotthing's actions delivered with simple locomotion were interpreted as we expected them to be showing the communicative power of simple nonverbal motion designed according to our principles.

Moreover, simple actions of a low/non-anthropomorphic robot have a compelling social communication power affecting the perception of animacy, likeability, helpfulness, and collaboration of a robotthing. Social-gaze movements and deictic gaze-movements achieve animacy and influence the robot's likeability and the perception of helpfulness of the robot behavior, especially when combined (Study 2, Chapter 4). Motion alone can be 'louder' than sound when trying to communicate help-giving intentions during child-robot collaborative play. Interestingly, children perceive giving and taking of a robotthing as helpful in a conflict situation. Especially so when the actions have a sine-wave motion style. At the same time, children endow more prosocial qualities to a giving action than to a taking action, which for children embodies antisocial qualities, despite being perceived as helpful in a conflict situation. We find that a sine-wave motion style interplays with the robotthing action endowing prosocial intentions and qualities and boosting the perception of helpfulness of a robotthing.

Lesson Learned

However, we also yielded results we did not anticipate. The unexpected results brought relevant insights into how children perceive low/non-

anthropomorphic robots. In line with the theory we have reviewed (Chapter 2, our findings are affected by the idiosyncratic ways children read and interpret agents [3]. In study 4 (Chapter 4), we provide early indications that children have a specific way to interpret robothing behaviors that might deviate from what designers intend. We highlight that interacting multiple times with a robothing that shares objects impacts how children explain the behavior of the robothing. While a giving behavior of a robothing is seen as helpful and motivates children to help back, a taking behavior is not perceived as unfavorable, even though children sanction it in the task. In Study 6 (Chapter 8) we show that giving and taking actions of a robothing are not perceived both as a helpful and collaborative act in a conflict situation like in Study 5 (Chapter 7). An insight we gather is that more consideration should be given to children's Theory of Mind of robothings and the other children involved in the interaction to deliver robothing communication that is perceived as intended. The perception of a low/non-anthropomorphic nonverbal behavior is considerably affected by interaction dynamics and the sequences of actions in the interaction with much variability. We have learned from Study 6 (Chapter 8) that more attention should be given to understand the interplay of social and task dynamics between children, as they might play a role in the way children perceive the robothing behaviors. While we did not investigate it empirically, we determine that the perception of a robot's nonverbal behavior during group interaction should also be evaluated on a group level, not only on a child level.

Despite the limitations, we have contributed rich insights into how children interpret and perceive low/non-anthropomorphic robots' non-verbal behavior in play. Minimal-movements and robothing's actions delivered with simple locomotion have a compelling social communication power that needs to be unpacked further, taking into account children's way of making sense of a robot's behavior in context.

9.1.5 RQ5. *What Method is Suitable to Co-Design the Non-verbal Behavior of a Robot with Children?*

The ways children interpret and perceive robots' nonverbal behavior might surprise (and have surprised) designers and researchers. In the dissertation, we actively investigated how to bridge the knowledge gap between designers and children. Crucially, we sought to understand how to facilitate the emergence of the tacit knowledge children have about their experience and perception of robots—a complicated question to pose, given the scarcity of cHRI literature.

To answer our question, we perused the literature on children's agency development and the CCI and cHRI literature. Through analysis of the CCI and design-research fields, we identified co-design as an approach providing a framework for methods that facilitate children's co-creating and reflecting about a robot's behavior and agency. We worked on translating

the theory into co-design activities by reviewing existing methods and techniques. We gathered that focusing on pretend play activities would support children's creativity and reflection, particularly role-play and perspective-taking exercises. Moreover, we conclude that embodied activities could support children's cognitive unloading and enable them to express their views about a robot's agency. Hence, we deemed co-design methods based on role-playing and perspective-taking as suitable to co-design the nonverbal behavior of a robot with children.

To answer our question, we had to understand and illustrate how children make sense of agents and robots. Subsequently, we had to step away from the HRI and cHRI discipline and investigate the CCI and design-research fields to look for suitable methods to facilitate children's expressions of their sense-making. We worked on translating the theory into co-design activities by reviewing existing methods and techniques. As existing methods are scarce and do to focus precisely on generation and reflection on a robot's behavior, we developed an ad-hoc-method. We built upon prior work and the literature of co-design with children. We called the resulting method Perspective Taking in Embodied Role-Play (PeerPlay). The method consists of two activities: (i) Exploratory PeerPlay is an activity for the initial design process, which entails body-storming and puppeteering (ii) Behavior-Authoring PeerPlay is an activity for the prototyping phase in which children author a robothing's behavior by puppeteering a tangible mini-robothing controller.

Insights

We gathered insights about the PeerPlay method in two workshops (Chapter 5). Each workshop was focused on one of the two main activities of the method. In Exploratory PeerPlay activities, children could express their tacit knowledge about how a robothing should behave in collaborative play with children. One of the workshop's insights is that puppeteering with a robot putter and taking a second-person perspective, and role-play in a tangible scenario with a proxy to better children express themselves. It produces a rich set of nonverbal behavior prototypes that designers could further analyze. We have identified three categories of motion elements that children used to "design" the behaviors: goal-directed motion, motion parameters, and direction of the motion. We have noticed that many of these motion elements are recurrent. The low-fidelity prototype could provide cHRI researchers with several motion elements to use as building blocks of a robot's behaviors. The reflections could support the decision-making in the design process, motivating design choices with children reflections. The Exploratory PeerPlay activity is low-fidelity, low-cost, and portable; thus, it could be easily implemented to explore robot behavior design.

Another exciting insight is that children build a "*character*" for a robot to explain its behavior, attributing social qualities to it to motivate specific actions. A robot is deemed angry when scattering objects around, for example. We even find some indications that motion elements such as the motion parameters are sometimes associated with positive and negative social attributes. Children often use the term "happy" for a light, indirect,

and sustained locomotion. Other times, they associate bossiness with heavy, direct, and sudden locomotion. The answer's variability makes it challenging to conclude on children's character-building tendency. Therefore, we interpret these insights cautiously as a definite pattern in the children's responses is missing. However, we believe that these insights are relevant and should be explored further.

The Behavior Authoring Workshop findings indicated that while promising, the Behavior Authoring PeerPlay activity is not yet sufficiently attuned to children's cognitive abilities and motor skills. Children found it hard to author the robot behavior because they experienced poor usability and poor user experience with Brobotino, a tangible mini-robot controller proxy. Apart from technical challenges, we think that it is too complicated for children to puppeteer the actions of a real robot with a mini-robotting controller. We suggest that the activity should be simplified and scaled to the variety of fine-motor skills of children. Moreover, the usability issues hamper children's reflections about each other design making it difficult for designers to understand children's sense-making and behavior explanation. Despite the challenges that children experienced while engaging in Behavior Authoring, we noticed that the activity, even with its flaws, stimulated children to express their points of view about the robot's behavior and the narrative behind the interactions. We anticipate that with a better-designed proxy and enhanced activity, Behavior Authoring could be an asset for cHRI research to co-design behaviors with children.

Lastly, we believe that PeerPlay (both activities) could support children and designers to collaborate in suspending the disbelief in fruitful ways. cHRI designers could also use the method to inform the narrative and scenarios in which interaction with a robot unfolds. Given that children tend to expand their explanation of enacted behaviors to a story related to the robot's intention and social qualities, designers could engage in a responsible co-pretense that does not cause deception.

Reflections

Reflecting on the PeerPlay method as a whole, the method involved children as informants specifically for the design process's early stage. However, we anticipate that – similar to what happened in CCI – children's role could be broadened to a full design partnership, in which children are involved during the whole design process. Our insights suggest that we would need to democratize the child-robot interaction design practices to make them more accessible to children for a complete design partnership. Otherwise, children would experience the same challenges we have observed in the Behavior Authoring PeerPlay activity; thus, it would be too difficult for children to collaborate with the researchers. Our attempts to author behaviors had mixed successes even if delivered with a very child-friendly and potentially appropriate activity. On the other hand, Exploratory PeerPlay is a promising activity that researchers can use to kick-start the cHRI design process. Moreover, we think that Exploratory PeerPlay could be used to explore how children understand a robot's mind and explore which behavior

children trust by enabling in-depth reflection about robothing intentions and intelligence.

PeerPlay lays the groundwork for designing a robot's agency responsibly, mindful of the ethical and social implication of deception and mismatch of children's expectations. Co-designing a robot's agency by engaging children in co-pretense exercise could help cHRI designers embed a fruitful suspension of disbelief in cHRI. Further developments of PeerPlay should support children in grasping what it means for a robot to interact with them autonomously, the boundaries in the suspension of disbelief, and how to critically explain the social intention of a robot.

Simultaneously, the PeerPlay method could be considered laborious by cHRI researchers because it increases the number of activities to carry out with children, a notoriously tricky target group involved in research activities. Moreover, cHRI researchers might find PeerPlay inefficient because it produces many qualitative data that needs to be systematized, parsed, and distilled into cHRI design insights. However, we believe that the quality of the insights that the Exploratory PeerPlay activity and, to a lesser extent, the Behavior-Authoring PeerPlay deliver justifies the effort because it enables a window into the way children make sense of robots. We do only apply PeerPlay to the design of nonverbal behaviors for low/non-anthropomorphic robots. Still, we anticipate that it could apply also to the verbal behaviors of human-like robots.

All in all, we cannot claim this is a validated method yet. More systematic evaluations of the method are needed with a more significant and diverse cohort of children. Nevertheless, we conclude that a co-design method that entails activities focused on perspective taking and embodied role-play enables children to co-design a low/non-anthropomorphic robot's nonverbal behavior. To the best of our knowledge, PeerPlay is one of the first co-design methods developed explicitly for cHRI, combining the co-creation of robot behaviors with an in-depth reflection of a robot's agency.

9.1.6 RQ6. *What are the Effects of a Robothing Behavior on the Prosocial Behavior and Collaboration of Children in Play?*

One of our main aims was to investigate how robothings could promote children's collaboration through play. We posited in our conceptual framework (Chapter 2) that a way to impact collaboration is to promote prosocial behaviors. Therefore, we investigated the effects of a robothing prosocial behavior (or opposite) on children's prosocial behavior and collaboration in collaborative play. This question is the most exploratory of all due to the extreme scarcity of prior research on the matter, at least with children. In our conceptual framework, we postulate that a robothing's prosocial behavior will entice children to reciprocate directly and indirectly and promote more sharing and helping in play, thereby promoting collaboration.

Empirical Insights

To answer this question, we have carried out two behavioral studies with children: Study 4, a longitudinal case-study (Chapter 4) and Study 6, a cHRI study (Chapter 8). On a behavioral level, we find evidence that a robothing can entice children to be more prosocial and collaborate more. Study 4 showed that children reciprocate a robothing directly and indirectly and tend to help a robot more when they play with a robothing that behaves prosocially. The robothing appeared to establish the norm of collaboration among the children, who kept reciprocating to each other and with the robothing in follow-up sessions. Simultaneously, we showed that when the robot breached the norm of collaboration, children sanctioned the robothing by stopping to share with it. In study 6, we have provided the first indications that a robothing strategy to intervene in a children's conflict impacts both at perception and behavior level. A prosocial strategy, operationalized as a giving action with sine-wave motion-style, positively impacts children's perception of helpfulness and collaboration with a robothing and a child and on prosocial behavior in the game after the intervention. We have found that a robothing that intervenes in a conflict with a prosocial strategy (i.e., giving an object children do need) is perceived as more helpful after the game. Children perceived themselves to have been collaborating more with the robothing when the robothing intervened with a prosocial strategy. The prosocial strategy of a robothing impacts how helpful children perceived the other child to be too. Moreover, children perceived to have collaborated more with the other child when the robothing exhibited the prosocial strategy. Children helped, shared, and informed each other more when a robothing acted prosocially. Therefore, there is an indication that a prosocial strategy of a robothing might compel children to be more prosocial in the game. Another crucial aspect that had an essential role in our results is children's actions happening *after* the conflict was elicited before the robot's intervention. Children appeared to respond either by taking the last piece of the puzzle for themselves or not taking any action. We found that a child's actions impact children's perception of helpfulness and collaboration with the other child in the game. Children who did not take the last piece of the puzzle perceived the other child, the one who did take it, as less helpful at the end of the game. Behavioral results of Study 6 show that a robothing intervention in a conflict appears not to impact the way children share the reward of a game or help the robothing after a game. Our forced behavioral measures, share-test and help-test, show that children share the reward of a game with each other and help the robothing irrespective of the robothing's intervention. Moreover, children perceived to have collaborated less with the child who did take the last piece. This insight is relevant to the literature on robots in groups; we need to consider the effects of a robot's intervention and the ripple effect (at the emotional and behavioral level) of this intervention and the task [353]. Research in HRI has shown that a robot's behavior causes a ripple effect in a team, but our results show that we need to factor in the other humans' behaviors in

the group. It is especially salient when studying HRI and cHRI in-the-wild [185]. To the best of our knowledge, this is the first account in the cHRI literature of the positive effects of low/non-anthropomorphic robots that interact nonverbally in cHRI.

Reflection

We raise the concern that we should have paid more attention to the sequencing of a robothing behavior in multiple sessions. Children appear not to perceive negatively a robothing that stops helping (Study 4 (Chapter 4) even though they stop to play with it. In our experiments, the interaction between children and robothing was dictated by the game mechanics we devised to test the robothing effects on children's prosocial behaviors and collaboration. Therefore, we cannot anticipate how the findings might replicate in more open-ended situations. Play is often unpredictable, and the robothing intervention might not keep up with the fuzziness of real-world play interactions. Moreover, our WoZ study design might have failed to account for possible robothing malfunctions and errors. Therefore we cannot speculate on the effect of interacting with an autonomous robothing. At the same time, we carried out only two studies on the effect of robothings with a limited cohort of children, all coming from western culture. To have a comprehensive overview of the effectiveness of robothings in promoting prosocial behaviors and collaboration in play, we need to carry out more tests in various contexts and with various participants.

The complexity of running studies with children in ecologically valid settings is very high. We needed to create an ad-hoc protocol for the setting and control many potentially fuzzy variables with our game design. As a result, one can raise a concern about how well our protocols in Study 4 and Study 6 represent naturally occurring playing behaviors. We could not afford to let the game unfold for experimental reasons, and the robothing is participating in the whole game. The game turns needed to be forced with the game mechanics, and the robothing behaviors minimized to the prosocial and coercive interactions. While we believe that these studies have given realistic insights about the potential dynamics between robothings and children, future work must study more in-the-wild and uncontrolled situations, as suggested by Hinds and Jung [185]. While aware of the limitations in ecological validity, we think that our protocol approximated reasonably a real-life game situation and gave relevant insights for future work. To the best of our knowledge, ours was one of the first attempts to study mobile robots interacting with children, and we offer protocols to the cHRI community.

Overall, robothings promote prosocial behaviors and reciprocity of prosocial behaviors and stimulate collaboration among children in play. However, more studies are needed to determine the definitive impact of robothing on collaboration.

9.1.7 *Conclusions: The ABCs of Robothings*

Our first aim was to investigate how robots with less human-like forms and behaviors can support children's collaboration by promoting prosocial behaviors through play. We wanted to step away from the current status quo of tutoring robots, focusing on delivering interventions like the ones children receive at school, which have relevant limitations. We shift our perspective to playful paradigms to promote children's collaboration in children's natural way through playful experiences with peers. We have shown that delivering prosocial behavior interventions with a robbing can impact children's prosocial behavior and reciprocity, thereby promoting collaboration. Despite the limitations and open questions that emerged in the research, we have shown that a playful intervention with robbing behaviors can go a long way, actively encouraging children to help each other and share more, which is pivotal in collaboration. We have provided a coherent conceptual framework of a robbing's intervention to promote children's collaboration with robots that are not humanoid and do not communicate in human-like ways. We provide rich empirical insights into how rothings influence children's behavior in play, and we identify key lessons learned and critical aspects to work on for future work.

Our second aim was to probe the design space of non-anthropomorphic nonverbal communication in child robot interaction. We focused on the communication in 'human terms' rather than communication in human-like ways, and we have contributed to taking the current state of the art a step further. To this end, we have synthesized a conceptual framework of robbing communication, which we operationalized into actionable principles. We designed a set of minimal nonverbal behaviors and robbing actions according to our principles. We gathered empirical evidence that shows that the robbing behavior legibly communicates and impacts children's perception in the way we expect from our designs. While probing the design space of non-anthropomorphic nonverbal communication in child-robot interaction, we embarked on a methodological exploration to involve children in the design process. The result of the design space explorations and methodological exploration is a proof-of-concept robbing and the co-design of its behaviors with children. While we realize there could be many other ways to design a low/non-anthropomorphic nonverbal behavior to communicate a robot's intention to children and that there are limitations to our approach, we gathered relevant insights to define further the design space of non-anthropomorphic nonverbal communication in cHRI.

Together these six questions contributed to addressing the two aims of the dissertation, thoroughly covering the 'ABCs' of rothings to promote children's collaboration in play. While our findings have limitations, we have contributed to an evolutionary broadening of cHRI in particular and HRI at large.

9.2 IMPLICATIONS

We have already reflected on and discussed the dissertation's findings, and we have related them to the HRI and cHRI literature. In this section, we hone-in on the implications of the main findings of the research. We outline implications for theory, design (both design of social robots and robots behaviors), and methods.

- Implications for Theory in Human-Robot Interaction.** Our work has implications for theory in HRI. First, we contribute with insights on how children perceive low/non-anthropomorphic behaviors. We show that minimal gaze-movements and actions delivered with locomotion are perceived socially when integrated into a social interaction around games. Second, we contribute findings on how children respond to low/non-anthropomorphic prosocial behavior and robots' behaviors to intervene in conflicts. We show that low/non-anthropomorphic behavior influences sharing, and helping behaviors stimulate reciprocity and collaboration. Lastly, even if tangential, we show that the theory on how human-communication evolved from nonverbal behaviors and how humans have developed a psychological infrastructure to make sense of nonverbal cues outlined by Tomasello [361] and Malle [240] can be applied to the study of human-robot communication. Tomasello's theory can primarily support research efforts to understand how a robot's communication should evolve.
- Implications for the Design of Robots Behaviors.** Our interaction design guidelines and design principles have implications for cHRI and HRI designers that investigate low/non-anthropomorphic robots' communication. While we have focused only on the children's population and the context of play, we anticipate that many of the insights we provide could apply to other domains. At a general level, we offer an alternative take on designing nonverbal behaviors for robots. Designers could apply our principles to go beyond the dichotomy between pragmatic and expressive motion and consider all the motion of low/non-anthropomorphic robots as potentially socially communicating. We provide to HRI designers a set of validated minimal gaze-movements and locomotion movements that socially communicate to children and could be implemented on other platforms by their simplicity. Moreover, we provide insights into the role of the motion-styles of a robot's locomotion. HRI designers can further explore a sine-wave motion style to reinforce a robot's locomotion's prosocial communication. Lastly, we provide design researchers with lessons learned. For instance, we should design the correct grounding of a robot's nonverbal behavior in the interaction and not only for legibility. Furthermore, we should design a robot's nonverbal behavior in sequences. While human-like robots and human-like robot communication behaviors are

arranged in patterns derived from human-human communication, for low/non-anthropomorphic robots, designers might need to explore the unique nonverbal ‘syntax’ and ‘nonverbal semantic’ of nonverbal communication as shown in our research.

- **Implications for the Design of Social Robots.** In the dissertation, we did not set to design robots per se, but we focused more on the design of robothing behaviors. Nevertheless, we eventually ended up designing our proof-of-concept robothing, Push-one. We believe that both the research on designing robothings behavior and designing Push-one have implications for social robots’ design. By showing that complex prosocial communication can be achieved with minimal motion and locomotion, we lay the groundwork for more low/non-anthropomorphic robots for children. Designers can develop a robot with minimal communication affordances without losing social communication power. Moreover, we show how to design from children’s co-design outcomes, providing an in-depth account of translating low-fi prototypes into functioning robothings. The process we have undertaken with a movement-centered approach shows how to design for form/function/behavior adherence and familiarity. Even though we did not empirically test the children’s perception of Push-one’s appearance, designers can explore abstract shapes and add non-anthropomorphic functional features to robots for children; the studies with Push-one (Study 5, Study 6) corroborate the idea that a non-anthropomorphic robot is appropriate to communicate with children in play socially.
- **Implications to Methodology in cHRI.** We suggest that cHRI designers should pay extra attention to the way children make sense of a robot’s behavior and should devote part of the design process to children. cHRI designers could use co-design as a window to children’s Theory of Mind of robots, which can help design behaviors attuned to children. We provide cHRI designers with some early insights on how to co-design with children. We show that the methods and techniques from other disciplines can be applied to cHRI with the necessary changes. We provide cHRI designers with a method called PeerPlay. Although the method is not entirely validated, PeerPlay can be further explored to help children enact a robot’s motion and reflect on their designs. In so doing, we can democratize social robots’ design for children and genuinely involve children in the process. We show designers how to analyze co-design outcomes and distill robots’ behaviors from low-fidelity puppeteering of robothing behaviors.

9.3 LIMITATIONS

The research presented in this dissertation is primarily exploratory. We have ventured to an uncharted territory of cHRI, dealing with extraordinary

design and methodological challenges. Carrying-out research with children is complicated because practices and methods from general HRI often do not apply to the children population [25]. Moreover, evaluation methodologies need to be attuned to the level of cognitive and behavioral development of children, which is prone to high variability even in small samples of participants [243]. As a result, the research presents some limitations. In this section, we critically discuss the limitations of the research. We hone-in on the limitations of working only with remotely controlled robothings, the potential generalizability limits of the findings, and the generalizability of the behavior design. Finally, we elaborate on the limitations regarding ecological, internal validity, and ethics.

9.3.1 *Robthings are not Autonomous Agents (yet)*

In Chapter 4, Chapter 6, Chapter 7 and Chapter 8, we have designed and evaluated the behaviors of various robothings. While in Chapter 4, we have worked with pre-existing platforms, in Chapter 6, Chapter 7 and Chapter 8 we have focused on Push-one, a proof-of-concept robothing that we have designed and developed.

Both pre-existing platforms and Push-one were not autonomous. The development of hardware and software necessary for a robothing to behave autonomously was outside the dissertation's scope. However, researching platforms that are not autonomous raises concerns about the applicability of the designs and findings. In HRI, designers often resource to the remote control of simple prototyping platforms or to video and animation studies to explore a wide range of design options without the time, and technical constraints of hardware and software development [151, 228]. Developing a fully functional autonomous robot is costly. Producing a fully autonomous robot without having tested beforehand on less costly platforms with less costly protocols (i.e., WoZ) of evaluation is often not sustainable.

Autonomous robothings' behavior and interaction might slightly deviate from what has been tested in the dissertation. Notwithstanding this limitation, we think that the HRI and design knowledge produced in this dissertation applies to autonomous robothings with a fair degree of fidelity. HRI research demonstrated that working with remotely controlled robots or simulations of robots is a good approximation for autonomous robots [151]. Moreover, part of the dissertation informed the development of an autonomous robothing, the Squirrel robot ². The research presented in Chapter 4 was directly applicable in developing the behaviors of the Squirrel Robots with minimal deviations.

All in all, we are aware of the limitations of not working (yet) with fully autonomous robots. Nevertheless, by adhering to best practices in HRI and

² <http://www.squirrel-project.eu/home.html>

exploring how to translate findings to an autonomous platform like the Squirrel robot, we have mitigated this limitation.

9.3.2 *Generalizability of the Findings and Behavior Design*

This dissertation presented six empirical studies (Study 1, Study 2, Study 3, Study 4, Study 5, Study 6) to answer our research questions. Five of the studies evaluated the design of robothings behaviors and their effects on children's prosocial behaviors and collaboration. In Study 2, Study 3, Study 4, Study 5, Study 6, we evaluate the design with three various robothings platforms (i.e., Festo Robotino, Squirrel Robot, Push-one)

The limited number of robothing platforms might raise issues of the generalizability of the findings. In other words, it might be challenging to assess how well the results we yielded apply to other robothings or low/non-anthropomorphic robots at large. The generalizability issue of platform-specific findings is well known in HRI [18]. Although we did not compare multiple platforms by being minimal and related to actionable principles, our robothings behaviors can virtually apply to low/non-anthropomorphic platforms that afford locomotion and rotation of the base. For example, the gaze movements behaviors of Study 2 (Chapter 4) have been used as a starting point of research in minimal movements for abstract robots [8].

At the same time, given our scope, we have only empirically tested the behavior of and interaction with robothings with the children population. A question is how well the findings can generalize to the adult population. We have extensively covered in the dissertation how children have a different way to perceive and explain animacy and agency [3]. Therefore, we do expect some developmental differences between children and adults. Outside the scope of this dissertation, we have started to examine the potential developmental differences between children and adults, replicating some of the VHRI studies (Study 2, Chapter 4) and Study 5, Chapter 7 observing some differences and some commonalities. We leave a comprehensive investigation of developmental differences to future research.

9.3.3 *Ecological, Internal, Face Validity*

Carrying out design explorations in HRI research is challenging, especially with children. To test a wide array of robot behavior prototypes, HRI employs prototyping methods that simulate the interaction with a robot [151]. At the same time, carrying out rigorous laboratory studies with children is not easy [235]: it is difficult for children to come to a laboratory, and laboratory studies are often not child-friendly. A child might feel intimidated by an unfamiliar environment; therefore, a child's behavior might deviate from laboratory studies' norm. Researchers are often adapting their protocols to in-the-wild situations, recreating laboratory settings in children

settings, like schools or after-school programs [193]. Evaluation metrics need to be attuned to children's cognitive development too. Questionnaires and metrics developed for adults cannot be used in the same format and wording as with children. Children might not be able to understand them. Simultaneously, surveys cannot explore a too wide array of metrics as children might quickly lose focus [243]. Therefore, to carry out our research, we have adopted a set of prototyping and evaluation methods attuned to the scope and the population of the research, raising concerns of ecological validity, internal and face validity.

In two studies (Study 2, Chapter 4, and Study 5, Chapter 7), we have evaluated our behavior prototypes in VHRI studies. VHRI is a widely used method to prototype robot behaviors both with adults and children. VHRI has the great advantage of presenting children with highly controlled, highly uniform stimuli. VHRI allows us to address hypotheses and research questions in a controlled way, and we can be relatively sure that our experimental variables cause the effects obtained. All in all, VHRI produces high internal validity. Besides, VHRI allowed us to reach a relatively large sample size of children, which is uncommon in cHRI [25]. However, the main drawback of VHRI is that children do not experience the robot, and they are not the ones interacting with the robot, but they watch an actor. Although VHRI promotes a 3rd person and indirect interaction, HRI and CHRI results appear to be reliable [268]. Moreover, we took all the precautions to mitigate these effects and create immersive videos. While VHRI suffers from poor ecological validity, high internal validity is beneficial for prototyping robot behaviors. Moreover, in our research, we have always followed up VHRI studies with in-person and in-the-wild studies (Study 4, Chapter 4, and Study 6, Chapter 8) to evaluate behaviors in context.

The behavioral studies (Study 4, Chapter 4, and Study 6, Chapter 8) that followed the VHRI studies were all WoZ studies. WoZ is an established approach in HRI [297], which yields reliable results. However, WoZ studies might raise issues with internal validity. A researcher remotely controls a robot can be subject to subtle variations because reproducing identical motion is not easy. In our studies, we mitigated the potential internal validity concerns of the WoZ approach by formulating scripts and running long training sessions at the locations of the experiment with the researchers responsible for the WoZ. Therefore, we ensured relatively consistent behavior across experimental sessions.

Lastly, in all the studies presented in the dissertation, we have used measures and survey items attuned to children's cognitive development. In other words, while in some cases we have used established metrics and instruments developed for the children population (Study 4, Chapter 4, and Study 6, Chapter 8), we have adopted items modified to children's levels of reading and comprehension. However, our measures could raise face validity concerns because some were explicitly developed for the experiments. We reached an appropriate level of reliability of instruments used, and we

consider our findings to have a reasonable degree of validity. Nonetheless, face validity in cHRI on and CCI [243] remains challenging.

9.3.4 *Ethics and Moral Implications*

One of the dissertation's main goals is to design for and with children to support children's flourishing. We design robothings that are not supposed to substitute teachers or friends by instructing or tutoring children. We have devised the robothings' intervention in collaborative play supporting children's independent reflection about prosocial behaviors without determining a right or wrong action to take in collaborative play. We focused on play with peers to enable children to provide an opportunity to play, an activity often overlooked in our educational systems. Moreover, we know from the literature that children learn about collaboration through play with peers. We involve children in the design process to embed their perspectives and views in robotic technology design.

Even though we have designed and researched children's welfare and development in mind, we did not do a thorough ethical analysis of our scenarios, interventions, and behaviors, nor have we assessed the long-term implications of such a technology on children's development. Ethical assessments were beyond the research scope, but we are aware that to continue this research line, it is necessary to ideate and design morally. We know from the literature of the philosophy of technology, and post-phenomenology in particular [374], that the objects surrounding us shape our perceptions, the way we make sense of ourselves and the worlds. Even the least autonomous technology, like a chair, mediates our experience in the world and shapes how we make sense of it. As a result, robothings will inevitably impact the way children make sense of collaboration and prosocial behaviors. It is necessary to discern the moral impact of robothings and assess whether the behaviors of the robothing are too normative and prescriptive. Without proper analysis, we might embed, even if implicitly, norms and values that negatively impact children's development. We live the analysis of moral and ethical implications for future work.

9.4 FUTURE WORK

The dissertation has probed the design space of non-anthropomorphic nonverbal social communication and investigated how bots with less human-like forms and behaviors can promote children's collaboration through play. The topics we covered, the design explorations we conducted, and the findings we yielded lay the groundwork for new research avenues. In this section, we discuss future work directions that stem from the dissertation.

9.4.1 *Towards a Theory of Robots Communicating in Human-Terms*

In the dissertation, we have studied what it means for a robothing to communicate in ‘human terms’ socially. By breaking down complex human communication theories and synthesizing collaboration and prosocial behaviors, we have identified the critical elements for communication in human terms. We have translated those elements in principles for simple movements of a robothing to readily communicate their intention to children. While our empirical findings corroborate the proposed framework and principles, we do not extensively explore the role of the motion style of a robothing behavior nor how a series of robothing behaviors should be sequenced in the interaction. Future work needs to unveil those aspects of communication in ‘human terms’. Ultimately, communicating in ‘human terms’ suggests that robots could develop their ‘language’. Instead of replicating human language or human behaviors, HRI and cHRI could further explore robot-specific communication methods.

However, we should first understand the applicability of robothings communication outside the cHRI setting. We did not test with adults or in a context outside of collaborative play, leaving exploring potential developmental differences and applying other scenarios to future work. An open question for future work is understanding the psychological determinants that make children or adults interpret a robothing’s motion differently.

All in all, more and more HRI research is concerned with enabling robots that are non-anthropomorphic and nonverbal to communicate with humans. Our published findings have already enabled more research on how robots can communicate in ‘human terms’ [8]. It would be timely and relevant to proceed into this research line towards a theory of robots communicating in ‘human-terms’.

9.4.2 *Studying the Interplay of a Robothing Appearance and Behaviors*

One aspect that we did not empirically research is the potential interplay of how a robothing looks like and its behaviors. In this dissertation, we have given prevalence to the robothings’ behaviors. Even when we have designed our proof-of-concept robothing, we started to design the behaviors, and *afterward* we have considered the robothing appearance through a movement-centered design process. However, we are aware that the appearance of a robothing might impact human-robothing communication that we did not empirically study. HRI has unveiled how humans tend to anthropomorphize anything that moves contingently or has minimal and abstract human-like appearance [18]. Researchers have swung between product-like appearances [299] to retain the familiarity humans have with everyday objects and ad-hoc appearances that stem from a robot’s behavior to design a low/non-anthropomorphic robot. Our principles dictate that familiarity and form/function/behavior adherence should be considered when designing

the interplay between the surface appearance and the robot's behaviors. However, we did not empirically study it in the dissertation. We believe that studying the interplay of a robothing appearance and behaviors will shed light (or tease apart) their combined effect on robothing communication.

9.4.3 *Robothings in Other Domains*

Robothings are hybrids between objects and social robots that leverage their nonverbal communication affordances. While in this research, we have only focused on robothings to promote children's collaboration in play, the design space of robothings could be broadened to other domains. Increasingly, researchers are exploring robotic technology in the healthcare and well-being domains to support behavior-change [299]. Robothings are well-positioned to deliver interventions that are not patronizing people like wearable technology often does [345], but enable people to be intrinsically motivated to change their behavior [380].

Outside this dissertation's scope, we have explored how robothings could increase serendipity and motivate people to communicate more with each other. We have contributed to the development of Bubble-Bot [223], a robothing capable of influencing humans' interpersonal behaviors enabling serendipitous interactions among people by bursting bubbles at people. Another example is the Snoozle [381] a robothing we have developed to influence people to maintain consistent bedtimes. Overall, the health and well-being domains offer an exciting test-bed for robothings that is worthwhile to explore.

9.4.4 *Making Robothings Autonomous*

The Robothings in this dissertation are all remotely controlled. Therefore, we did not investigate how to deliver robothing's behaviors autonomously. While a robothing's behaviors appear simple in terms of movements, to deliver such behaviors, a robothing needs to have a sophisticated set of sensing and social signal processing capabilities to understand when and how to intervene in play.

For example, work related to this dissertation has explored how to use speech, visual features, and emotional cues to detect children's engagement in a collaborative task, a useful metric to know when a robothing should deliver a behavior [199]. Other work related to this dissertation considered how to endow the Squirrel robothing with the ability to recognize the position of objects in the space on-the-fly and dynamically [213] and modulate the movements to push an object smoothly, considering the friction with the floor or other variables [210].

Future work should focus on what type of sensing, perception, and reasoning capabilities a robothing needs to engage with children in play.

Technical constraints might change the envisioned robothing's intervention and downsize the communication robothing affords. Therefore, it is essential to understand how to develop autonomous robothings to truly discern the applicability of robothings outside of the design research realm into real-world scenarios.

9.4.5 *Co-design Explainable Robothing Behaviors*

Recently, there have been relevant developments towards making robots and other autonomous agents 'explainable' so that humans might have a more trustworthy interaction with them [134]. For disembodied artificial intelligence agents, explainability has mainly to do with endowing agents with the ability to explain what decision an agent takes and why, and how its algorithms work [134]. For robots, explainability has to do with making robot behavior comprehensible and in line with expectations [128].

Within the development of the PeerPlay method, we have *indirectly* touched upon the explainability of robothing behaviors. We have focused mainly on facilitating children's expression of a robothing should move to communicate its intention and explain how they perceive their designs in terms of the agency of the robothing. The method enables researchers to understand how children would like a robothing to communicate specific intentions in an interaction context and how children would make sense of the agency's perception of those behaviors. An essential follow-up of the PeerPlay method is a co-design activity that can tap into children's ways to explain the agency of a robothing in a context, its intelligence, and their expectations interaction with a robothing. PeerPlay could support designers and children to discuss the illusion of a life of robothings and robots in general.

9.4.6 *Responsible Child-Robot Interaction*

Robotic technology influences the way we behave and how we perceive the world around us [374]. Designing robots for children raise numerous ethical concerns, especially because children are still in development. The culture, norms, and values that designers directly or indirectly endow robots shape how children make sense of reality, with potentially adverse effects on children's development. Therefore, designers have a responsibility to envision the ethical implications of child-robot interaction.

The exploration of robothings has indirectly touched upon ethical challenges. A robothing is supposed to mitigate some of the pitfalls of humanoid tutoring robots, such as deception. Moreover, by focusing on play, robothings' intervention favors the natural ways children learn about collaboration. However, we did not thoroughly assess the ethical implications of interacting with a robothing. In our research, we did not examine whether intervening

on prosocial dynamics impacts the way children take moral decisions; or whether influencing children's conflict dynamics might have ethical ramifications. Throughout our research effort, it became apparent that the ethical sphere of the design of child-robot interaction cannot be an afterthought.

To understand how to work towards responsible practices in child-robot interaction, we have organized various international workshops in various academic venues. While the workshops have been pivotal to raise awareness and share best-practices, little is known about how researchers can anticipate the ethical repercussions by design. A ripe avenue for future work is thus responsible for child-robot interaction research.

9.5 CONTRIBUTIONS

This section outlines the dissertation’s scientific contributions and elaborate briefly on the potential impact of the findings beyond academic boundaries.

Drawing from Wobbrock [400] classification of contributions in human-computer interaction, we identify the following contributions:

1. **Contributions to Theory:** We contribute with a conceptual framework to design robothing communication to influence prosocial behavior in collaboration. Our framework is a vehicle to systematize and provides actionable guidelines and principles to research the communication and interaction with robothing. We validate our framework in empirical studies with children. We cannot anticipate whether the conceptual framework will extend similarly to adults and other domains; Moreover, we provide a minor contribution to the theory of prosocial behaviors, showing how children reciprocate and prosocially behave with robots.
2. **Empirical Contributions:** We contribute with quantitative and qualitative findings of the communicative power of robothings’ behaviors and the effects of interacting with robothings. We gathered rich insights about how children interpret and perceive robothing behaviors, providing evidence that minimal-movements and actions delivered with locomotion are legibly communicated to children. Furthermore, we provide insights on how children perceive robothings’ actions and motion-style. Lastly, we provide early evidence that a robothing can promote reciprocity and prosocial behaviors enabling collaboration in play;
3. **Artefact Contributions:** We contribute a set of validated robothing behaviors for cHRI, which could extend to HRI and HCI. Moreover, we contribute a robothing proof-of-concept artifact that researchers can use to carry out cHRI research; both hardware and software are available as open-source. The artifact is designed according to our conceptual framework and principles.
4. **Methodological Contributions:** We provide first insights about how to co-design robothing behaviors with children. We contribute with a co-design method, PeerPlay, that other researchers can use to design robots robots’ nonverbal behaviors with and for children and reflect on a robot’s agency with them. Even though our method is not fully validated, we think it could contribute to further the methodological discourse in cHRI, HRI, and potentially HCI.

Lastly, we expect the impact of the dissertation to reach fields outside academia. With our work, we opened up avenues for designing the socially

interactive toys of the future. While developing a product was beyond the research scope, we offer a window to the future of educational toys, both in terms of interventions and communication design. We enabled an intervention centered on play, which is often overlooked in children's education. Moreover, we show that playful interventions with embodied agents that play with natural objects are a promising avenue for socio-emotional learning beyond computer and tablet applications.

9.6 CONCLUDING REMARKS

We live in a world where interactive technology will increasingly play a role in the life of children. The challenge is to design technology for children that maximizes the benefits and minimizes the potential harm. We show that robothings can positively impact children's prosocial behavior in collaboration. Robothings present a promising intervention in children's learning of collaborative skills, which are expected to become an essential asset of 21st-century life. Simultaneously, the dissertation shows that designing for children demands focusing on what is meaningful for and attuned to how children develop.

By touching upon the complexity of designing for children, the research highlights the necessity to start a multidisciplinary discussion. Multiple disciplines should investigate developmentally appropriate interventions, explore child-centered methodologies, and consider democratizing more child-robot interaction practices, which should be morally driven. The studies presented in the dissertation greatly benefited from less common methods in HRI and children's inclusion in the design process. Human-robot interaction should collaborate more with children and with the stakeholders of technology for children. Researchers and children should collaborate for a future in which technology enables children in charge of their socio-emotional learning through play.

The dissertation shows that we have just scratched the surface of robothings for child-robot interaction. By shifting the focus to robot communication in 'human terms', we have contributed to child-robot interaction research with potential new communication models, new forms of robots, and new interaction paradigms. The dissertation findings are somewhat limited to the robothings platforms we tested and the interaction context we explored. Despite the limitations, the dissertation corroborates the notion that robots with less resemblance to humans, both in form and communication, can interact socially and impact children's social behavior. Implicitly, the research encourages rethinking what a robot's social communication is, what shape and social roles a robot can and should take. Robots do not have to look and behave like us, nor to take on human-roles. They should be a prosocial technology that supports human flourishing and is designed with ethical implications in mind.

We are aware that we are touching upon the 'tip of the iceberg' of the potential of robothings, but we believe in having contributed, to some extent, to the evolutionary broadening of the human-interaction design field with a promising new avenue of research.

APPENDIX

A.1 CHAPTER 4

A.1.1 *Study 4: SDQ questionnaire in English*

For each item, please mark the box for Not True, Somewhat True or Certainly True. It would help us if you answered all items as best you can even if you are not absolutely certain. Please give your answers on the basis of the child's behavior over the last six months or this school year.

Child's name:

Male/Female:

Date of birth:

- Considerate of other people's feelings. Not True ☐ Somewhat True ☐ Certainly True ☐
- Restless, overactive, cannot stay still for long. Not True ☐ Somewhat True ☐ Certainly True ☐
- Often complains of headaches, stomach-aches or sickness. Not True ☐ Somewhat True ☐ Certainly True ☐
- Shares readily with other children, for example toys, treats, pencils Not True ☐ Somewhat True ☐ Certainly True ☐
- Often loses temper Not True ☐ Somewhat True ☐ Certainly True ☐
- Rather solitary, prefers to play alone Not True ☐ Somewhat True ☐ Certainly True ☐
- Generally well behaved, usually does what adults request Not True ☐ Somewhat True ☐ Certainly True ☐
- Many worries or often seems worried Not True ☐ Somewhat True ☐ Certainly True ☐
- Helpful if someone is hurt, upset or feeling ill Not True ☐ Somewhat True ☐ Certainly True ☐
- Constantly fidgeting or squirming Not True ☐ Somewhat True ☐ Certainly True ☐
- Has at least one good friend Not True ☐ Somewhat True ☐ Certainly True ☐

- Often fights with other children or bullies them Not True ☐ Somewhat True ☐ Certainly True ☐
- Often unhappy, depressed or tearful Not True ☐ Somewhat True ☐ Certainly True ☐
- Generally liked by other children Not True ☐ Somewhat True ☐ Certainly True ☐
- Easily distracted, concentration wanders Not True ☐ Somewhat True ☐ Certainly True ☐
- Nervous or clingy in new situations, easily loses confidence Not True ☐ Somewhat True ☐ Certainly True ☐
- Kind to younger children Not True ☐ Somewhat True ☐ Certainly True ☐
- Often lies or cheats Not True ☐ Somewhat True ☐ Certainly True ☐
- Picked on or bullied by other children Not True ☐ Somewhat True ☐ Certainly True ☐
- Often offers to help others (parents, teachers, other children) Not True ☐ Somewhat True ☐ Certainly True ☐
- Thinks things out before acting Not True ☐ Somewhat True ☐ Certainly True ☐
- Steals from home, school or elsewhere Not True ☐ Somewhat True ☐ Certainly True ☐
- Gets along better with adults than with other children Not True ☐ Somewhat True ☐ Certainly True ☐
- Many fears, easily scared Not True ☐ Somewhat True ☐ Certainly True ☐
- Good attention span, sees work through to the end Not True ☐ Somewhat True ☐ Certainly True ☐

Signature

Thank you very much for your help

A.2 CHAPTER 7

A.2.1 *Code for Push-one Behaviors*

```
#include <math.h>
```

```

#include <WickedMotorShield.h> //from open source Wicked repository
Wicked_DCMotor m1(M1);
Wicked_DCMotor m2(M2);
Wicked_DCMotor m3(M3);

#define RC1 4 //Radio control inputs
#define RC2 8 //Let's avoid magic magic numbers

long ch1;
long ch2;
bool breaked = false;

int mode = 1;
float s = 0; // time in seconds, updated in loop

void setup() {
  Serial.begin(115200);
  Serial.print("<3");
  pinMode(RC1, INPUT);
  pinMode(RC2, INPUT);
  setBreaksOff();
}

void loop(){
  // Time in seconds
  s = (float) millis() / 1000.0f;

  // Read Remote Control
  ch1 = pulseIn(4, HIGH, 25000);
  ch2 = pulseIn(8, HIGH, 25000);

  // If the remote is acting weird or is turned off, the value of ch1 is 0
  if (abs(ch1) < 1) {
    Serial.println("REMTOTE ERROR");
    // then breai the motors.
    if (!breaked) setBreaksOn();
  } else {
    // start moving again if the breaks were on:
    if (breaked) setBreaksOff();

    // This centers the values
    ch1 = ch1 - 1500;
    ch2 = ch2 - 1550;

    int vy = map(ch1, -460, 440, -1000, 1000); // FORWARD / BACKWARDS
    int vx = map(ch2, -460, 420, 1000, -1000); // LEFT / RIGHT

    // threshold the input, so the robot is still when it's just in the center...
    if (abs(vy) < 300) vy = 0;
    if (abs(vx) < 300) vx = 0;

    Serial.print(vx);

```

APPENDIX

```

    Serial.print("\t");
    Serial.print(vy);
    Serial.print("\t");
    if (mode == 1) {
        behaviorSmooth(vx, vy);
        Serial.println("SMOOTH");
    } else if (mode == 2) {
        behaviorErratic(vx, vy);
        Serial.println("ERRATIC");
    } else {
        behaviorNormal(vx, vy);
        Serial.println("NORMAL");
    }
}
}

// Sine-wave motion style
void behaviorSmooth(int vx, int vy) {
    float phasesOverTime = 1.5;

    // How strong are the curves:
    float amplitudeOfRotation = 300;

    // Combine for angular motion
    float angularMotion = amplitudeOfRotation*sin(s*phasesOverTime);

    if (vy <= 0) angularMotion = 0;

    setMotors(vy, 0, vx + angularMotion);
}

// Jerky motion style
void behaviorErratic(int vx, int vy) {
    // the higher, the more often it's switching the back/forth
    float phasesOverTime = 3;

    float magnitudeMotion = 300+300*sin(s = phasesOverTime);
    if (vy <= 0) magnitudeMotion = vy;

    if (vy > 0 && magnitudeMotion < 100) magnitudeMotion = -300;
    if (vy > 0 && magnitudeMotion > 300) magnitudeMotion = 800;

    setMotors(magnitudeMotion, 0, vx);
}

// Linear motion style
void behaviorNormal(int vx, int vy) {
    setMotors(vx, 0, vy);
}

/* Parameters:

```



```

* magnitude: how fast to move in the direction (a value between 0 and 1000)
* dir: angle of the direction (in degrees) relative to the robot orientation.
* rot: angular motion (a value between 0 and 1000)
*
*/
void setMotors(float magnitude, float dir, float angularMotion) {
    // Normalize the magnitude such that the total speed is the same...
    // ...not sure if this is perfect:
    float correctedMagnitude = magnitude - abs(angularMotion);

    // Formula from
    //http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.99.1083&rep=rep1&type=pdf
    float w1 = correctedMagnitude * sin(rad( 0 - dir)) + angularMotion;
    float w2 = correctedMagnitude * sin(rad(120 - dir)) + angularMotion;
    float w3 = correctedMagnitude * sin(rad(240 - dir)) + angularMotion;
    // 0 / 120 / 240 define the frame of reference of the robot.
    // i.e. setting dir to 0 means that motor 1 won't turn
    // we're turning in direction of motor 1.

    m1.setDirection(w1 < 0 ? DIR_CCW : DIR_CW);
    // If w0 is smaller than 0, motor goes CCW=counterclockwise..
    m2.setDirection(w2 < 0 ? DIR_CCW : DIR_CW);
    // For w1 we changed the sign to get it to rotate in the correct direction
    m3.setDirection(w3 < 0 ? DIR_CCW : DIR_CW); // ...

    // Map the computed motor speed to the control range.
    // i.e. a value of 1000 gets mapped to the maximum motor speed of 255.
    byte w1_speed = (byte) map(abs(w1), 0, 1000, 0, 255);
    byte w2_speed = (byte) map(abs(w2), 0, 1000, 0, 255);
    byte w3_speed = (byte) map(abs(w3), 0, 1000, 0, 255);

    m1.setSpeed(w1_speed);
    m2.setSpeed(w2_speed);
    m3.setSpeed(w3_speed);
}

// Enable breaks (stop)
void setBreaksOn() {
    m1.setSpeed(0);
    m2.setSpeed(0);
    m3.setSpeed(0);
    //m1.setBrake(BRAKE_ON);
    //m2.setBrake(BRAKE_ON);
    //m3.setBrake(BRAKE_ON);
    breaked = true;
}

// Enable breaks (allow driving)
void setBreaksOff() {
    m1.setBrake(BRAKE_OFF);

```

```

    m2.setBrake(BRAKE_OFF);
    m3.setBrake(BRAKE_OFF);
    breaked = false;
}

// Convert angles to radians;
float rad(float ang) {
    return ang / 57.29578;
}

```

A.3 CHAPTER 8

A.3.1 *Study 5: Empathy Index*

1. It makes me sad to see a girl who can't find anyone to play with.
2. People who kiss and hug in public are silly.
3. Boys who cry because they are happy are silly.
4. I really like to watch people open presents, even when I don't get a present myself.
5. Seeing a boy who is crying makes me feel like crying.
6. I get upset when I see a girl being hurt.
7. Even when I don't know why someone is laughing, I laugh too.
8. Sometimes I cry when I watch TV.
9. Girls who cry because they are happy are silly.
10. It's hard for me to see why someone else gets upset.
11. I get upset when I see an animal being hurt.
12. It makes me sad to see a boy who can't find anyone to play with.
13. Some songs make me so sad I feel like crying.
14. I get upset when I see a boy being hurt.
15. Grown-ups sometimes cry even when they have nothing to be sad about.
16. It's silly to treat dogs and cats as though they have feelings like people.
17. I get mad when I see a classmate pretending to need help from the teacher all the time.
18. Kids who have no friends probably don't want any.
19. Seeing a girl who is crying makes me feel like crying.
20. I think it is funny that some people cry during a sad movie or while reading a sad book.
21. I am able to eat all my cookies even when I see someone looking at me wanting one.
22. I don't feel upset when I see a classmate being punished by a teacher for not obeying school rules.

PUBLICATIONS

PUBLICATIONS INCLUDED IN THE DISSERTATION:

- **Zaga C.**, *Designing the future of education: from tutor robots to intelligent playthings*, Tijdschrift voor Human Factors, Volume 44, number 3, November 2019, The Netherlands.
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BIOGRAPHY OF THE AUTHOR

A portrait of the author by the Italian illustrator and artist Fortuna Todisco.

Cristina Zaga was born in Novara (Italy) and lived in Milano (Italy), Vienna (Austria), Brooklyn (NY), Trento (Italy), Enschede (NY), and Ithaca (NY). She has studied Humanities and Communication Science (BA *summa cum laude*) while working in the media and creative tech 'scene' in Milano. She worked as a UX researcher, social media specialist, and journalist for newspapers and magazines alike in a previous life. She co-founded one of the first Italian food design magazines, *EssenTaste.com*; she co-wrote an award-winning fashion film, ghostwrote for many Italian authors, and featured in an Italian TV series about young journalists.

In 2012, she decided to shift her focus to academia when her bachelor thesis analyzing Italian Twitter's linguistics got published straight after the thesis defense. Her research showed how the auto-generated Twitter grammar (e.g., hashtags and mentions) influenced Italian grammar. Thanks to her multidisciplinary profile, she was selected for the prestigious Cognitive Science Master at the Cimec in Rovereto/Trento (Italy) with a full scholarship at the excellence College Bernardo Clesio. In 2014, she obtained a double master's degree in Cognitive Science and Human-Media Interaction (*summa cum laude*) after spending half of her master's at the Human-Media Interaction Group (University of Twente, The Netherlands). Her thesis on Engaging Child-Robot Interaction was published in a conference paper in 2015. Continuing her graduate studies as Ph.D. candidate, Cristina has worked as a research associate at the Human-Media Interaction Group (University of Twente) under Prof. dr. ir. Vanessa Evers and dr. Khiet Truong in the context of the European FP7 Project Squirrel. She was a visiting scholar at the Robots in Groups Lab led by dr. Malte Jung (Cornell University, USA) to work her doctoral research about "robothings", everyday robotic objects, and toys that promote children's prosocial behaviors in collaborative play.

Currently, Cristina is an assistant professor, speaker, and maker of robots. At the Human-Centred Design Group (led by prof. dr. ir. Mascha van der Voort) and The DesignLab of the University of Twente (led by dr. Sabine Wildevuur), Cristina's research bridges engineering, design, and social science to develop technology responsibly. She investigates methodologies, tools, and techniques to connect science and society through transdisciplinary responsible design of technology. She is particularly interested in developing co-design and speculative design methods to imagine, ideate, and design robots responsibly. Cristina believes in poetic computation's power to bring about future-oriented reflection on the technology we want to develop. She collaborates nationally and internationally with various researchers to advance responsible robot design and bridge HRI and design research.

Her award-winning work in Human-Robot Interaction has received many academic and societal accolades. Her work, the Snoozle robot, and the Push-one robothing have been exhibited at the Eindhoven Design Week. She is regularly invited as a keynote speaker at events (e.g., TEDxDarsena, TEDxUtwente, Leonardo LaserTalks, Waag events, Twente Open Days).

Cristina is the recipient of the University of Twente Social Media Award as she believes science communication is fundamental to bring science to society. Cristina regularly publishes and organizes international workshops in top-tier conference venues (CHI conference, HRI conference, CSCW conference). She is heavily involved in academic service for ACM SIGCHI, currently CHI2022 video preview co-chair. Cristina is an intersectional feminist and social justice proponent. She advocates for technology that is diverse and inclusive. Cristina was selected as Google Women TechMaker Scholar 2018, receiving an award and scholarship for her research quality and her efforts to make STEM more inclusive to women and children.

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