Exploring Multidimensional Trust

Shaping Child-Robot Creative Collaborations in Education

NATALIA CALVO BARAJAS
Abstract

As trust plays a pivotal role in maintaining long-term interactions between children and robots, it is vital to comprehend how children conceptualise trust and the factors influencing their trust in robots. This thesis examines the impact of social robots' behaviours and attributes on children's trust, relationship formation, and task performance in collaborative educational scenarios. A systematic review of child-robot interaction (cHRI) literature identified two primary dimensions of trust: social trust and competency trust. The literature suggests a lack of consensus about how different robot behaviours and attributes affect these two dimensions of trust, as evidence points to different directions. To address these gaps, a collaborative storytelling game was developed to facilitate interactions between children and social robots, aiming to study trust dynamics and enhance learning by fostering children's creativity. The research also examined the impact of robot-related factors, such as behaviour and appearance, on children's interactions with robots. Empirical evidence suggests that while making robots look and behave more like humans is critical for competency trust and task performance, lower human-like attributes are more crucial for developing social trust and relationship formation with robots. Other factors, like time, provide insights into children's trust dynamics. Thus, this thesis explores the role of repeated interactions with artificial agents, indicating that children's competency trust in robots changes over time. This thesis offers significant contributions to the cHRI community. Firstly, it demonstrates that trust is a multidimensional construct that is complex to capture, highlighting the need for reliable, objective measures tailored to the task and intended trust dimension. Secondly, it emphasises the importance of balancing human likeness with social robots when collaborating with children in educational scenarios. Lastly, it proposes that to sustain trustworthy long-term interactions in education; social robots should adapt their behaviour to provide scaffolding, as children will be more inclined to rely on them for learning support as time progresses.

Keywords: child-robot interaction, social robots, trust, educational robotics, creativity, children perception of robots

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Dedicated to all the fearless women, whose unwavering resolve and steadfast commitment illuminate the path to a more just and equal world.
This thesis is based on the following papers, which are referred to in the text by their Roman numerals.

I  A meta-analysis on children’s trust in social robots.  

II "And then what happens?" Promoting Children’s Verbal Creativity Using a Robot.  
Maha Elgarf², Natalia Calvo-Barajas², Patricia Alves-Oliveira, Giulia Perugia, Ginevra Castellano, Christopher Peters, and Ana Paiva in *Proceedings of the 2022 ACM/IEEE International Conference on Human-Robot Interaction* (pp. 71-79), 2022.

III Hurry up, we need to find the key! How regulatory focus design affects children’s trust in a social robot.  

IV The effects of robot’s facial expressions on children’s first impressions of trustworthiness.  
Natalia Calvo-Barajas, Giulia Perugia, and Ginevra Castellano in the *29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)* (pp. 165-171), 2020, IEEE.


¹ Authors contributed equally and shared first authorship  
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VI "I have an idea!" Enhancing children’s verbal creativity through repeated interactions with a virtual robot.
Natalia Calvo-Barajas and Ginevra Castellano in *Proceedings of the 22nd ACM International Conference on Intelligent Virtual Agents* (pp. 1-8), 2022.

VII Understanding Children’s Trust Development through Repeated Interactions with a Virtual Social Robot.
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Author Contributions

The following discusses the contribution by the individual authors to the publications included in this thesis.

I  I collaborated with Rebecca Stower on an equal basis, and we are the principal authors of this paper. Our co-authors provided comments and input specifically on the discussion and final version of the manuscript.

II I collaborated with Maha Elgarf on an equal basis, and we are the principal authors of this paper. We were responsible for designing the experiment, implementing the software interface and robot’s behaviours, collecting and annotating the data, engaging in discussions to analyse the data and results, and writing the paper. Our co-authors participated in regular discussions throughout the process, focusing on elaborating on the study’s coding schemes, results, and writing.

III I am the principal author of this paper. I collaborated with Maha Elgarf on designing the experiment, implementing the software interface and robot’s behaviours, and collecting the data on a 50% basis. I was responsible for developing and validating the objective measures, data analysis, and writing the paper. My co-authors provided input to the final version of the manuscript.

IV I am the principal author of this paper. With input from Ginevra Castellano, I designed the experiment and the different stimuli for the robot. Giulia Perugia and I collected and analysed the data together. I held the primary responsibility for writing the paper. Throughout the process, all co-authors participated in regular discussions on the study’s design, results, and progress.

V I am the principal author of this paper. I designed the experiment with input given by Ginevra Castellano. I designed and carried out the validation studies and implemented the robot’s behaviours. Together with Anastasia Akkuzu, we collected and annotated the data. I had primary responsibility for the data analysis and writing of the paper. Ginevra Castellano participated in regular discussions on ideas and results and provided continuous feedback on the manuscript in progress.
VI I am the main author of this paper. I was solely responsible for designing and implementing the experiment, collecting and analysing the data and writing the paper. Ginevra Castellano participated throughout the process in regular discussions and provided input to the final version of the manuscript.

VII I am the main author of this paper. I was solely responsible for designing and implementing the experiment, collecting and analysing the data and writing the paper. Ginevra Castellano participated throughout the process in regular discussions and provided input to the final version of the manuscript.
Related publications

In addition to the papers included in this thesis, the author has also written and contributed to the following publications:

i  **Can a Social Robot Be Persuasive without Losing Children’s Trust?**

ii  **Reward seeking or loss aversion? impact of regulatory focus theory on emotional induction in children and their behavior towards a social robot.**

iii  **The effects of Motivational Strategies and Goal Attainment on Children’s Trust in a Virtual Social Robot: A Pilot Study.**

iv  **Interdisciplinary research methods for child-robot relationship formation.**

v  **CRITTER: Child-Robot Interaction and Interdisciplinary Research.**
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1. Introduction

The implementation of new technological development in the last decade is moving fast. As a result of the widespread use of technology in daily activities, researchers from various fields have focused on making it trustworthy and reliable. In the human-robot interaction (HRI) context, several questions arise regarding how to increase users’ trust in social robots, improve robots’ transparency and trustworthiness, and assess the potential consequences of over-trust in robots. For instance, understanding when and why these situations occur is essential to ensure the safe and effective use of robots. Over-trust may result in users relying too heavily on a robot’s capabilities, ignoring their own knowledge and experience, or overlooking potential dangers [1]. While there are many studies on how adults interact with robots and the implications for trustworthiness perception, there are unanswered questions about how children perceive robots in terms of trustworthiness.

Education is a field that has had significant changes due to innovation and technology. Social robots are one type of technology used as educational tools to assist children in various tasks, as their physical presence seems beneficial for increasing cognitive and affective learning outcomes compared to other technologies [2]. Social robots are physically embodied agents capable of interacting and communicating behaviour and intentions [3]. In an educational scenario, a child and a social robot may collaborate on specific tasks, with various signals providing information about the interaction’s success and the robot’s effectiveness as an educational companion. For example, when solving a maths problem, children may consider the information provided by the robot as reliable for task completion [4]. In a second language learning activity, children may mimic the words uttered by the robot to learn new vocabulary [5]. However, not only cognitive outcomes are essential in child-robot educational interactions. Children’s knowledge experiences are constructed through interactions with the world, people, and objects [6, 7], meaning that social aspects of the interaction play a critical role in learning. Therefore, if robots are intended to interact socially with children, understanding the implications of social robots and how children perceive them may help to develop and design more trustworthy technology and AI.

In child-robot interaction (cHRI), trust towards social robots is essential, as it may be a decisive factor in sustaining successful and long-term interactions that contribute to implementing such technologies in the classroom. Social robots embody different physical appearances and social behaviours (verbal and non-verbal), leading to many robot-related factors influencing children’s
trust in robots. Thus, examining the social and cognitive capabilities inherent in social robots could provide insights into how children consider robots trustworthy companions. However, to deeply study the factors affecting children’s perceptions of the robot’s trustworthiness and their interaction with these agents, it is crucial first to investigate how children conceptualise trust and the roles they assign to social robots in collaborative scenarios. Also, examining other constructs, such as closeness, engagement, and liking, could provide more information about the various social and cognitive processes involved in learning. Consequently, this thesis aims to better understand how trust is defined and captured in child-robot interaction and to investigate how robot-related factors such as appearance and behaviour impact children’s trust and their behaviour towards robots in a collaborative creative task.

This thesis comprises five studies, described in seven papers, that contribute to achieving its goal. The first study aimed to establish a foundation for studying trust in cHRI by conducting a meta-analysis on children’s trust in social robots, as presented in Paper I. The objective of the second study was to design and develop a collaborative storytelling task with social robots to investigate verbal creativity as the learning outcome (Paper II) and children’s trust in robots (Paper III). Studies three and four focused on investigating how robot-related factors, such as facial expressions of emotion (Paper IV) and human likeness in terms of physical appearance and behaviour (Paper V), influence children’s trust in and their behaviour towards robots. Lastly, study five evaluated the effect of repeated interactions on children’s verbal creativity (Paper VI), trust dynamics, and relationship formation (Paper V). Throughout these studies, various subjective and objective measures were implemented to capture children’s trust and relationship formation with social robots and their effect on verbal creativity within the context of a real-world storytelling task implementation.

Throughout the course of these studies, the multidimensional nature of trust in cHRI emerged—social and competency trust. Moreover, the complexity of capturing trust was examined, suggesting that subjective and objective measures can lead to different outcomes. This work demonstrated that utilising objective measures specifically tailored to the task and nature of the interaction in cHRI enables a more precise assessment of children’s trust in social robots. The significance of a robot’s appearance and behaviour, based on human-like attributes, was investigated. Results indicate that human likeness in social robots may have diverse effects on the different dimensions of trust in cHRI. As such, achieving a balance in human likeness for social robots is vital. It might optimise both social and competency trust, leading to more effective and trustworthy interactions within collaborative tasks. Lastly, the effect of time was explored and discussed. Findings demonstrated that children’s trust in the robot changes as time evolves. This observation highlights the importance of considering temporal dynamics in trust development when designing child-robot interactions. In conclusion, this thesis provides recommendations for
developing and implementing robot-related factors, collaborative tasks, and measures in cHRI to foster trustworthy interactions in educational scenarios.

1.1 Thesis Structure
The work of this thesis, detailed in 7 chapters, aims to provide a more comprehensive view of how trust is investigated in cHRI and which factors influence trust, learning, and child-robot collaboration. Chapter 2 offers extensive background on children’s learning, the role of robots in education, and the examination of children’s trust in social robots. Subsequently, Chapter 3 introduces the research questions addressed in this thesis, along with a summary of the methods employed and their relation to the studies and publications included in this work. Various factors were manipulated to answer those research questions to gather empirical evidence through user studies. Chapter 4 describes the apparatus, stimuli, and experimental setups utilised in these empirical studies, as well as the manipulated independent variables. Chapter 5 presents the results and individual contributions of the publications included in this thesis. This is followed by Chapter 6, which discusses the results of each publication. Finally, Chapter 7 provides the conclusions, limitations, and recommendations for future work.
2. Theoretical Background

This thesis’s primary focus is modelling children’s trust in social robots. In order to contextualise the role of trust in child-robot educational interactions, this chapter reviews the relevant background literature concerning the three central research topics of this thesis: the application of robots in education, the definition and conceptualisation of children’s trust, and the factors that influence trust in social robots.

2.1 Social Robots in Educational Scenarios

Computers have been used to support learning for more than 50 years. Seymour Papert and his colleagues were pioneers in introducing technology into the classroom. In the early 1970s, they developed the programming language LOGO for children to program computers while learning computational thinking, geometry, and maths [8, 9]. Building on Papert’s approach of using physical entities as constructs to facilitate learning experiences, robots began to be used as educational tools due to their power to engage children, especially in mathematics and science [10, 11]. However, there are other areas of education where robots could benefit learning outcomes, such as second language learning [12, 13], creativity [14, 15], and literacy [16] (See Figure 2.1 for examples of child-robot interaction scenarios). In such contexts, cognitive and affective mechanisms of social interactions are essential to support learning. Social robots are more likely to elicit social behaviours from users than other technologies [17, 18]; hence they hold great promise as educational and tutoring companions [2, 19].

Social robots are classified as social actors because they are designed to act on behalf of or in collaboration with humans, entailing human forms of social intelligence [3, 11]. According to the social intelligence hypothesis, for an agent to achieve socially intelligent behaviour in a dynamic social interaction, it must be embodied in both a physical and social environment [20]. Furthermore, social intelligence should also allow individual relationships to develop between agents [21]. In line with this, one of the first attempts to use robots in schools was carried out by Kanda and colleagues [22]. Their work examined whether children could form relations with social robots and learn from them over time. In a 2-week trial, children interacted with an autonomous robot “Robovie”, a humanoid robot capable of expressing human-like emotions and
gestures to communicate with humans [23]. The authors found that only children who developed a sustained relationship with the robot improved their English skills. This finding suggests that social robots will be more effective at supporting learning if they can establish relationships with children [22].

The advantage of social robots over other kinds of educational technologies stems from their physical presence, as evidence suggests that social interactions with physical artificial agents maintain children’s engagement in tasks more effectively than telepresent robots or virtual agents [17, 25]. However, the nature of social interactions introduces new challenges for cHRI, particularly technical challenges when implementing personalised robots in unconstrained environments. Social robots must be aware of their surroundings and accurately interpret children’s behaviours, responses, and social cues to fulfil their role as tutors or educational companions [26]. While autonomous robots exist for specific tasks and constrained environments [16, 27], research addressing all the social signals needed to support relationship formation and enhance engagement and learning is still in its infancy [28]. There are different types of personalisation, including robot behaviour and appearances. For instance, personalised social robots that respond to children’s verbal and nonverbal affective cues could improve engagement and maximise long-term learning gains [29]. However, these forms of adaptation are only occasionally beneficial to learning [30]. One reason could be that certain social behaviours may be distracting [31, 32]. Therefore, the robot’s social behaviour must be carefully designed in conjunction with the interaction context and task to improve educational interaction.

Overall, the potential benefits of social robots in positively impacting cognitive and affective learning outcomes have been investigated. However, carefully designing and implementing the robot’s behaviours, roles, and learning tasks are crucial to promoting child-robot relationships that support learning. In this context, assessing children’s perceptions of social robots as trustworthy artificial companions is highly important. This can contribute to a better un-
derstanding of optimally implementing robots in educational settings. Therefore, exploring the role of robot-related attributes in child-robot collaborative interactions becomes essential for evaluating children’s trust in social robots. This information provides insights into the processes involved when children rely on social robots to structure their learning experiences. These insights can guide the development of more effective and engaging educational technologies.

2.2 Children’s Learning and Development

When designing robots’ behaviours and educational tasks tailored to children’s needs to facilitate their cognitive and affective learning outcomes, it is crucial to have a solid understanding of the social and cognitive mechanisms underlying children’s learning and development. Psychologists and educators argue that learning is built through interactions and transactions with the world rather than merely acquiring information or transmitting existing ideas. This is known as constructivism, which proposes that knowledge is constructed by relating to others and acting in the world [33]. Jean Piaget is known as one of the pioneers of constructivism. According to his cognitive development theory, children have their own views of the world that are tailored to their current needs and interests, which differ from those of adults [33]. As children grow, their intellectual development progressively shifts from intuition to rational thinking. Piaget’s theory made significant contributions to education. A good teacher, thus, should help learners explore, express, and expand their views, as learning involves cognitive and affective mechanisms that emerge during interactions with the outside world. However, Piaget’s work has also been criticised for neglecting the relational aspect of cognition, as it did not consider that cognitive processes are influenced and shaped by social interactions, relationships, and cultural contexts [34].

Lev Vygotsky introduced the concept of socio-constructivism, suggesting that learning has a social component as one learns better by interacting with others [6]. In other words, he argued that the individual’s human intelligence is developed from the outside, through interactions with other people [35]. Vygotsky’s work implied that interactions with others help children develop cognitive skills, which become more sophisticated mental processes as they grow. Therefore, he stated that children learn more when guided by more knowledgeable others, adults in particular, which is explained by the so-called “zone of proximal development” [6]. Vygotsky believed that learning occurs most effectively within this zone, as the learner is challenged enough to promote cognitive growth but not so much that they become frustrated or discouraged. In addition, this way of learning is shaped and mediated by social interactions with others, accentuating thus the importance of relationships [36, 37, 38]. Vygotsky’s work has influenced teaching strategies in educational settings,
as teachers are encouraged to provide “scaffolding” to help children develop new skills [39]. Similarly, in scenarios where robots are used as technological tools, scaffolding can be implemented to assist learners in their cognitive development and skill acquisition [5].

With the incursion of digital technology into the learning environment, education needs to be adapted to unique challenges and needs. For instance, the introduction of computers and social robots may alter the nature of the learning processes as people perceive computers as part of their social and psychological lives, influencing their relationship with the world [40, 41]. Seymour Papert proposed the constructionism approach to learning in the classroom, which shares similarities with constructivism. Both view learning as a process of building knowledge structures through the progressive internalization of actions, essential to externalize ideas and feelings, a critical aspect of communicating with others. Moreover, Papert’s constructionism evokes the concept of learning-by-making, which indicates that learning is an interactive process by which learners negotiate meaning through tangible forms (e.g., computers, language, toys) that best support the exploration of their ideas [42].

While the constructionism principle was proven to be effective when the constructs are digital media or virtual entities [43]—software design is a constructionism activity that increases effectiveness in learning—it has unique effects on children’s learning when the constructs are physical artefacts, such as social robots because they allow children to sense and manipulate their environment to construct knowledge [19]. Interaction with robots involves social and cognitive processes that may affect children’s learning [19]. Furthermore, this interaction also involves interpersonal relations that can serve as precursors to the emergence of mental processes and knowledge, as proposed by Vygotsky [6, 7]. As a result, social robots offer new opportunities for creating learning environments that can assist children in enhancing their learning, for instance, providing various forms of scaffolding to adapt to children’s learning needs and progress [5, 44].

2.3 Children’s Trust
When assessing various characteristics to determine whom to trust, children’s evaluations are primarily influenced by two broad aspects of social cognition: competence and benevolence. Competence refers to an individual’s perceived ability or expertise in a particular domain, while benevolence pertains to the individual’s perceived goodwill and intentions towards others [45]. For instance, children are more inclined to endorse informants that provide smart and competent information [46]. This preference for competence is rooted in the children’s understanding that a more knowledgeable and capable informant is more likely to provide accurate information that can be relied upon. Children also consider a source’s benevolence when deciding to trust their in-
formation [47]. This evidence indicates that children’s trust is a multifaceted and fundamental personality trait with affective and cognitive dimensions.

Trust is critical for socially responsible behaviour, psychosocial adjustment, and intellectual achievement in child development [48]. Research has shown that children who trust others are more inclined to take risks and enjoy life experiences with objects, activities, and relationships. Building trust among children involves social acceptance by peers, friendship, and cooperative interactions [49]. Trust is also shaped by children’s relationships with parents and friends, which are interpersonal and can impact trust development [50, 51].

However, as children grow, moral reasoning and social expectations shape their perceptions of trust. While in early childhood, children’s trust is concerned with their own interests, which implies a rewards-punishment system in social interactions, older children focus on mutual understanding of friends’ needs and reciprocity [48, 52]. For example, Furman and Bierman found that children in second grade prioritised the importance of secret sharing, while fourth-grade children recognised the importance of reciprocal trust in friendships [50]. Therefore, a single definition of trust may not be enough to describe children’s trust across cognitive and social-emotional development.

Moreover, understanding how trust impacts children’s learning and interaction with their educational environment is essential, as trust predicts socially responsible behaviour and greater learning outcomes [53]. As such, trust also benefits performance and achievement in intellectual activities that are associated with concern with achievement [53, 54]. Trust in one’s teacher appears to correlate significantly to performance in reading, social studies, arithmetic, language arts, and science [55]. Hence, children who trust their teacher may perform better in class as they feel more confident in their knowledge and are more likely to ask for help [56]. These findings suggest that trust may influence classroom achievement by promoting socially responsible, compliant, and prosocial behaviour and predicts creative achievement by promoting personal commitment and flexibility in modifying strategies towards expected outcomes [57].

2.4 Empirical Evidence of Trust in cHRI

As described in the previous section of this chapter, social robots have embedded capabilities to recognise and display behaviours for social interactions that may affect the way people perceive and interact with robots in educational settings (for a more comprehensive review of how these behaviours affect learning see Belpaeme et al. [2]). One feature of interactions with social robots is that they can develop relationships [58, 59]. In HRI, each interaction involves a “personal and intimate relational dimension between a human and a robot” [60, p. 205], where the human-robot relationship involves trust for robots to be successfully accepted. To better understand the impact of robot-related at-
tributes on child-robot relationships and trust, it is essential to review how trust has been studied and operationalised in cHRI.

2.4.1 Definition and Measure of Trust

Studies on trust in HRI distinguish two dimensions to assess people’s trust in robots: capacity trust (reliable, capable) and moral trust (ethical, sincere) [61]. In cHRI, a group of studies have investigated children’s trust in robots akin to Rotter’s conceptualisation of interpersonal trust [62], as relying on another’s word or promises [63, 64]. Others have focused more on the perceived reliability of the robot, which includes elements of capacity trust [65, 66]. Another study distinguishes three types of social confidence (i.e., general trust, social judgement, privacy), which potentially incorporates some elements of integrity or morality [67]. Nevertheless, some cHRI studies do not define trust at all and measure trust more broadly (e.g., “Do you trust the robot?”) [68, 69]. These works frequently associate trust with other social constructs, such as empathy and acceptance, implying that trust in cHRI has been conceptualised primarily regarding social factors rather than reliability or competency.

While empirical studies investigating the multidimensional nature of trust are becoming more popular with adults (e.g., [70, 71]), only a few studies have applied this approach to investigate children’s multidimensional trust in social robots [72, 73]. Therefore, it needs to be clarified how to conceptualise trust in cHRI.

Various methods have been employed to capture children’s trust in social robots. For the more social aspects of trust, self-questionnaires [74], self-disclosure [75], and interviews [76] have been utilised. Meanwhile, the more cognitive processes of trust have been assessed through Likert scales [65], forced-choice techniques [63], and following instructions [17]. Despite the diversity of methods used to assess children’s trust in social robots, such as different subjective and objective measures [72, 77, 78], there remains a need for the development of more accurate and reliable instruments that can capture the complex nature of trust while also reflecting a developmentally appropriate definition of trust in childhood. Current methods, although helpful, may need to fully address the complexity of trust or how trust evolves in response to different robot-related and context-related factors. Thus, trust measures should incorporate multiple approaches to assess the affective, cognitive, and behavioural components of trust and should be tailored to the age, gender, and other demographic characteristics of the population [48]. Consequently, this thesis combines subjective and objective measures to capture children’s multidimensional nature of trust according to the main aspects of social cognition.
2.4.2 Factors Affecting Trust

In HRI, Hancock et al. [79] identified three factors impacting human-robot trust: human-related, robot-related, and environmental. Robot-related factors were found to be the most important, with robot performance and attributes having the most significant influence on human-robot trust [80]. In cHRI, a few studies have investigated child-related factors, such as age [81, 82], context-related factors, such as the role of the robot [83], and repeated interactions with the robot [66, 75, 28]. Attribute factors (e.g., robot personality, expressiveness, embodiment, and anthropomorphism) significantly impact the interpersonal aspect of trust. In contrast, performance factors (e.g., robot behaviour, failure rates, interaction length) contribute more to developing the competency dimension of trust [64]. Moreover, empirical evidence in cHRI indicates that robot-related factors have been studied in three main categories: Robot Embodiment, Robot Behaviour and Robot Errors.

**Robot Embodiment**

In examining robot embodiment, research can be divided into two categories: studies that compare a human and a robot [77, 76, 67, 84], and studies that compare different embodiments. The latter category includes comparisons between physical and virtual embodiments [85, 65, 17] as well as comparisons among various robot embodiments [69, 86]. Despite the empirical nature of these studies, the results remain inconclusive, as they have yet to identify any consistent, systematic differences. This may be due to the varied nature of the robot embodiments, interaction contexts, and participant demographics, which can all contribute to the inconsistent findings.

**Robot Behaviour**

Robot behaviour has been studied concerning verbal and non-verbal behaviours. The findings about how robot behaviour affects children’s trust are contradictory. In one study, an affective robot scored lower on social trust than a non-affective robot, according to [74]. In another study, children were less intimate with an energetic robot than a less energetic one [87]. Conversely, Breazeal et al. discovered that contingent robots were more trusted than non-contingent ones [88]. These studies have one fundamental difference: the latter focused on competency aspects of trust, whereas the former dealt with measures of interpersonal trust.

A more recent study has explored how children evaluate a robot’s behaviour, revealing that the reliability of the robot’s behaviour has significant implications for children’s interactions and task performance [89]. The study found that reliable behaviour improves task performance, whereas unreliable behaviour promotes more task-related social interactions. As a result, assessing how a robot’s behaviour affects the multidimensional nature of trust may help shed more light on the real significance of robot behaviour.
**Robot Errors**

The effects of robot errors are also the subject of some cHRI studies. For instance, Geisskovitch et al. found no consistent differences between reliable and unreliable robots on social and competency trust measures [63]. Weiss et al. looked into the credibility of a robot that gave a hint during a game and then showed whether it was right or wrong. They discovered a considerable decline in reliability when the robot was wrong [90]. Yadollahi et al. manipulated the type of error a robot made and measured children’s aptitude for identifying the robot’s errors (learning-by-teaching) [32]. Zguda et al. qualitatively investigated kids’ responses to a robot with a problem, revealing that kids either were unaware of or did not care about the robot’s failure [91]. However, although robot errors were a controlled variable in each of these investigations, only the first two contained quantitative trust evaluations [63, 90].

Overall, the current research on children’s trust in robots has yielded conflicting results. The concept of trust is complex, and studies have yet to agree on how to define or measure it accurately in the context of child-robot interaction. As a result, there are varying conclusions regarding children’s attitudes and beliefs about trusting social robots, and the factors that impact those beliefs remain unclear. One of the objectives of this thesis is to provide a more systematic and comprehensive investigation of trust in cHRI.
3. Research Questions

This thesis centres on the interaction between a child and a social robot, with the aim of obtaining a more comprehensive understanding of the child’s behaviour and performance in a collaborative learning task to study trust emergence, development, and maintenance in cHRI. Four research questions were identified to address gaps in the existing literature outlined below:

**RQ1: How is trust conceptualised and operationalised in child-robot interaction, and which factors affect children’s trust in social robots and how?**

To address this research question, a systematic review was conducted to organise existing empirical research and provide insights into current knowledge on children’s trust in robots. **Study 1**, a Meta-Analysis presented in Paper I, aimed to provide a concrete definition of children’s trust in robots along two dimensions: social trust and competency trust. Additionally, this study distinguished social trust from other constructs related to social attitudes, such as liking and friendship, that have been used to investigate children’s relationships with social robots. Furthermore, the study identified robot- and task-related factors that impact children’s perceptions of social and competency trust in robots.

**RQ2: How to design a collaborative task between a child and a social robot that supports learning while also being suitable for empirically investigating children’s trust?**

This research question has a two-fold objective: (1) to design and develop a collaborative storytelling learning task between the child and the robot, and (2) to evaluate the impact of this learning task on children’s perceptions of trust and liking towards the robot. Thus, to address this research question, **Study 2** was conducted.

When designing learning applications with social robots, it is important to consider the role of cognitive development in children’s learning. Therefore, the learning task developed in this thesis was aligned with children’s needs and developmental stages. Storytelling was selected as the primary activity
focusing on enhancing children’s verbal creativity as the desired learning outcome. Paper II describes the storytelling activity created for this thesis, which includes a software interface children used to tell their stories and a storyteller social robot. The storytelling activity was consistently employed throughout the user studies in this thesis, with some occasional additions or adjustments depending on the purpose of each study. The collaborative learning task is comprehensively described in Chapter 4, Section 4.1.

The second part of Study 2 investigates how robots’ behaviours could assist child-robot collaboration while sustaining engagement and learning. Therefore, Paper III presents the effects of interactive storytelling on child-robot collaboration by understanding the role of emotion-driven behaviour on children’s attitudes towards following a robot’s suggestions and their perceptions of the robot as a trustworthy learning companion.

RQ3: What is the effect of different robot-related factors on children’s social and competency trust, and how to capture the latter by using subjective and objective measures?

As discussed in Section 2.4.2, the existing literature suggests three categories for studying robot-related factors. To address RQ3, this thesis examines the impact of robot-related factors, specifically behaviour and embodiment, on children’s trust using subjective and objective measures. To achieve this, two user studies were designed as described below.

Study 3, presented in Paper IV, draws on the emotion theory to evaluate the effect of non-verbal behaviour as a human-like attribute, specifically facial expressions of emotions, on the emergence of trust towards a social robot.

Study 4, outlined in Paper V, was designed to investigate the effect of different levels of human-like attributes, in particular, the robot’s appearance and verbal behaviour during a storytelling task, on children’s perceptions of both social and competency trust, as well as their behaviour towards the robot. Subjective and objective measures were implemented to capture the different dimensions of trust and its relationship with story creation and task completion.

RQ4: How do repeated interactions with a social robot affect children’s learning and trust development in a collaborative task?

Trust theory suggests that trust can evolve as relationships develop. However, as the literature review indicates, research on children’s trust in robots has largely focused on single encounters, with limited exploration of children’s trust development in long-term interactions with robots. To address this gap, RQ4 seeks to investigate the development of children’s social and competency
trust towards social robots in repeated encounters. Thus, this research question also has a two-fold objective: (1) to evaluate whether storytelling is an effective learning task for fostering children’s verbal creativity in multiple interactions, and (2) to examine how these interactions with a social robot shape the emergence and development of children’s trust in robots. To achieve this, **Study 5** was conducted.

Developing a collaborative learning task that can be used in both single and repeated interactions helps further explore the emergence and maintenance of trust. The storytelling application was modified to support an online setup and assess verbal creativity through repeated interactions with a social robot, as presented in Paper VI.

Concerning the second objective of **RQ4**, the study investigated trust development in repeated interactions and its association with pro-social attitudes using both objective and subjective measures, as presented in Paper VII. The findings from **Study 5** contribute to the discussion of the emergence and maintenance of social and competency trust, in response to other factors, such as time.

To summarize, this thesis comprises four research questions that were addressed by conducting five studies presented in seven papers. Figure 3.1 illustrates the structure of the thesis concerning its research questions and clarifies how they are covered by the included publications.

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**Figure 3.1.** Summary of the main topics covered by the research questions in this thesis, organised by the included publications.
4. Apparatus, Stimuli, and Procedures

This chapter provides comprehensive information on the experimental procedures employed in the empirical work of this thesis, specifically in the user studies (i.e., Study 2, Study 3, Study 4, and Study 5). A summary of the methods utilised in Study 1 can be found in Chapter 5.

4.1 Study 2: Design of the Storytelling Learning Task

A collaborative activity was designed to facilitate interactions between children and social robots, enabling the collection of empirical data to address the research questions outlined in Section 3. The activity needed to support learning and provide a collaborative scenario to assess how robot behaviours, performance, and embodiment affect children’s social and competency trust and their relationship with the social robot during a learning task. Thus, a storytelling game was developed for Study 2, which paired a child with a robot to promote verbal creativity as a primary learning outcome. The storytelling system created as part of Study 2 was developed in collaboration with Maha Elgarf—Ph.D. student at KTH at the time.

Storytelling and Creativity

Storytelling, a widespread activity for fostering children’s verbal and social skills [92], has consistently been used to entertain young children. In cHRI, robot-assisted storytelling has been applied to support language development in children [53], to help children in therapy [93], and to promote creativity [14, 15]. As such, interactive storytelling with artificial agents enables various cognitive and social processes that can provide valuable insights when evaluating children’s trust in robots, either by assessing their robotic partner as a rational agent or its performance during the storytelling task. For the purpose of this thesis, the social robot served as a learning companion in the collaborative storytelling game. In other words, the social robot is not intended to be an intelligent tutoring system that already knows the answers about the subject being learned, but rather a collaborator that assists the child in learning through the interaction [19].

Within the educational context, interactive applications featuring artificial agents, such as virtual agents or social robots, are required to support children’s learning. Since the experiments presented in this work took place in an educational setting (i.e., children’s schools), the collaborative activity needed
to support learning innovatively. Creativity is considered one of the essential skills in children’s development [94]. Thus, the collaborative storytelling game presented in this thesis aimed to enhance the creative process in children. Hence, the learning outcome assessed in this work pertains to **verbal creativity**.

**Regulatory Focus Theory and Creativity**

The Regulatory Focus Theory (RFT) posits that people adopt one of two possible approaches when pursuing goals: promotion and prevention. In a promotion focus, individuals focus on attaining positive outcomes (e.g., excitement and happiness) related to the importance of fulfilling goals and aspirations (i.e., goal achievement motivation). Conversely, a prevention focus involves avoiding adverse outcomes (e.g., stress and anxiety) associated with maintaining safety and being responsible (i.e., failure avoidance motivation). Psychological research suggests that the promotion focus approach may elicit greater creativity than the prevention focus approach [95]. Focusing on positive outcomes may encourage individuals to explore novel ideas and take risks [96], whereas focusing on preventing negative outcomes may hinder creativity, leading to a more conservative mindset [97].

This study explored RFT as a design strategy related to emotion-driven design to create a storytelling game that promotes verbal creativity in children.

### 4.1.1 Development of the Priming Activity

According to Neumann [98], priming is a technique used in research to elicit emotions. Thus, the priming activity aimed to develop a game to induce emotions in children following two mechanisms based on the RFT [99]. The priming was developed as a pretend-play game between the child and the robot. In the game, children were instructed to imagine themselves locked in a spaceship with the robot on planet Mars. Their goal was to help the robot to find a key to get out of the spaceship. Because the objective of the priming was to evoke emotions people experience when goals are met, the design guaranteed that children always found the key and got out of the spaceship. Following the appropriate regulatory focus paradigms, two versions of the priming activity were designed. In the **promotion** version, children played a reward-seeking game in which they were promised a gift as soon as they escaped the spaceship—the gift was a party on planet Mars with the aliens. As **prevention** focuses on risk avoidance, in this version of the game, children and the robot collaborated to find the key to escape from the spaceship before an explosion. The children landed on Mars after escaping from the spaceship. Each version of the priming game had its own graphical user interface and robot behaviours, which will be described below.
Table 4.1. Samples of the robot’s verbal behaviours in the promotion and prevention versions of the activity, according to the priming stage.

<table>
<thead>
<tr>
<th>Version</th>
<th>Stage</th>
<th>Robot’s utterances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Promotion</td>
<td>Beginning</td>
<td>“I am so excited to do this!”</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>“I cannot wait to open the gift!”</td>
</tr>
<tr>
<td></td>
<td>End</td>
<td>“We’re finally on Planet Mars. I am so happy!”</td>
</tr>
<tr>
<td>Prevention</td>
<td>Beginning</td>
<td>“I am so scared of the explosion!”</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>“This is getting scary”</td>
</tr>
<tr>
<td></td>
<td>End</td>
<td>“I feel so much better now!”</td>
</tr>
<tr>
<td>Both</td>
<td>Any</td>
<td>“We should click on the arrow on the right!”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Oh we have a message! Can you read it?”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Go to red to find the key!”</td>
</tr>
</tbody>
</table>

**Priming: The Behaviour of the Robot**

The social robot used in Study 2 was EMYS, a robotic metallic head able to express emotions through facial expressions [100]. For the priming activity, the social robot displayed verbal and non-verbal behaviours to suggest happiness and excitement in the promotion version and fear and anxiety in the prevention version. The robot’s verbal behaviour consisted of different utterances that conveyed messages representing the regulatory focus emotions. In addition, the robot delivered verbal behaviours to provide guidance and request for action. These behaviours were designed to help children navigate through the game while eliciting collaboration and were equal for both versions of the priming game. Table 4.1 lists examples of the robot’s utterances.

Concerning non-verbal behaviours, the robot’s facial expressions were manipulated to exhibit emotions. The emotions displayed by the EMYS robot had been validated in a previous user study with children aged between 8 and 12 years [100]. The pre-defined EMYS fear and joy expressions were implemented for prevention and promotion accordingly. Figure 4.1 illustrates examples of the facial expression of the EMYS robot.

**Priming: Graphical Interface**

The graphical interface for the priming game was integrated using Unity Game Engine1. Each version of the priming game featured three scenes representing various spaceship rooms. Each room contained three coloured bottoms children clicked on to look for hints to find the key and two arrows that led to other spaceship rooms. Only the third room had the bottom containing the key; when children clicked on it, a final scene with planet Mars appeared. Additional details were incorporated to represent either the gift promised in the promotion version or the spaceship shaking to simulate the explosion in the prevention version. Children in the promotion version received the gift

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1https://unity.com
of a party with the aliens, whereas children in the prevention version escaped the explosion. To ensure equal exposure to the priming, the game’s dynamics were identical for both versions. Samples of the priming interface for both versions of the priming are shown in Figure 4.1.

Figure 4.1. Samples of the robot’s verbal and non-verbal behaviours and the graphical interface used for the Priming game in Paper II and Paper III. (a) EMYS facial expression of “joy”, verbal utterances, and the first room of the spaceship for the promotion condition. (b) EMYS facial expression of “fear”, verbal utterances, and the third and last room of the spaceship for the prevention condition. Children found the key to get out of the spaceship in this room, which applies to both game versions.

4.1.2 Development of the Storytelling Activity

In Study 2, the storytelling activity was developed to support children’s story creation and investigate the effects of RFT on creativity. It occurred twice during the study: before and after the priming activity. Children were asked to tell a story to the robot. The storytelling activity had a graphical interface and the robot’s behaviour to support store creation.

The Behaviour of the Storyteller Robot

In Study 2, the robot was an active listener that conveyed verbal utterances to give value and empathise with the child’s story. Different robot verbal behaviours were designed to provide guidance and support during the game and
Table 4.2. Samples of the robot utterances during the storytelling activity of Study 2 presented in Paper II and Paper VI.

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition and Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suggest</td>
<td>Offer for consideration. The robot suggests some ideas for the story. These mainly relate to the category of robot behaviour called “backup stories.”</td>
</tr>
<tr>
<td>Question</td>
<td>Expression of inquiry that invites a reply, e.g., “What do you think will happen now?”</td>
</tr>
<tr>
<td>Declare and Explain</td>
<td>State something and establish reasoning. The robot provides guidance and explains technical moves, e.g., “Now move your character” or “Let’s move on.”</td>
</tr>
<tr>
<td>Express</td>
<td>Abstract vocalizations that signal empathy and understanding, e.g., “Ohhh” or “Noooo.”</td>
</tr>
<tr>
<td>Value</td>
<td>Show encouragement, support, and value, e.g., “Wow, you are very good at this!” or “That’s a good idea!”</td>
</tr>
</tbody>
</table>

backup stories to prompt children to start telling the story in case they find difficulty during the activity. The robot’s behaviours and backup stories were a modified version of the scripts developed by [101]. Table 4.2 shows examples of the robot verbal behaviours used in the storytelling activity.

**Storytelling: Graphical Interface**

The graphical interface was created with Unity Game Engine to assist children in telling their stories to the robot. It included five topics with three scenes each. Besides, children could use a set of four characters and nine objects to tell their stories by moving them with their fingers. Two scenarios (castle and playground) with four characters (prince, princess, crocodile, and alien) were used prior to the priming activity, while three scenarios (beach, farm, forest) with four different characters (girl, boy, robot, dog) were used after the priming activity. The storytelling software was displayed on a touch screen between the child and the robot to facilitate collaboration and story creation, as shown in Figure 4.2.

4.1.3 Experimental Setup and Procedures

The study was carried during two weeks at two private schools in Lisbon, Portugal. The two primary researchers were always present during the data collection. They were responsible for conducting the experiment and following a strict procedure to guide children through the activity, deliver the questionnaires post-intervention, and teleoperate the robot. The experimental setup consisted of the child seated on a chair at one side of a table and the robot mounted on the other side of the table in front of the child. A touchscreen was
Figure 4.2. Experimental setup for the empirical study 2, presented in Paper II and Paper III. In this study, children interacted with the EMYS robot. The interaction consisted of three parts. The first was a storytelling activity, followed by the priming activity with either promotion or prevention conditions, and finalised with a second storytelling game. The game was displayed on a touch screen between the child and the robot.

Located between the child and the robot to display the corresponding activity’s interface, as depicted in Figure 4.2.

4.2 Study 3: Robot-related Factors, Non-verbal Behaviour

Anthropomorphism in HRI promotes more natural interactions and enhances collaboration [22, 102]. Human likeness, closely related to anthropomorphism, has been incorporated into social robots in various ways, including appearance and behaviour [22]. However, many social robots utilised in cHRI offer limited or no appearance customisation, resulting in manipulating a robot’s human likeness predominantly through its behaviour [103].

The research presented in this thesis seeks to comprehend the manner and extent to which a social robot’s human-like features influence children’s trust in the robot. However, manipulating human-like behaviour is not sufficient to cover the spectrum of the effect of human likeness on children’s trust in and liking of social robots. Hence, it was essential to find a robotic platform—apart from the EMYS robot used for Study 2, Section 4.1—that (a) fulfils the requirement of manipulating human-like features for physical appearance and behaviour, (b) is suitable for interactive collaboration with children in educational scenarios, and (c) can be used in online setups if needed. Several studies have investigated the promise of mixed embodiments, as they have the advantage of displaying the behaviours of a physical robot, with the potential
to alter the robot’s appearance and model facial expressions similar to virtual characters [104]. Based on this promising characteristic, the decision was taken to consider further the suitability of mixed embodiments to study the effects of human likeness on trust. The second version of the Furhat\(^2\) robot was chosen for this thesis. Furhat is a human-like robotic head equipped with a rigid mask with a facial texture projected from within. The robot has three degrees of freedom that allow it to orientate its head in the 3D space [105].

**Emotions and Trust**

The first human-like attribute investigated in this work was non-verbal behaviour regarding facial expressions of emotions, corresponding to Study 3 and presented in Paper IV. Non-verbal behaviour plays a crucial role in building trustworthy tutor-learner communication, and it is essential to know which cues learners use to evaluate others [38, 106]. Similarly, in cHRI, non-verbal emotional behaviour can elicit trust and closeness in children towards robots [5, 107]. However, two aspects of emotions might also influence children’s trust: the type of emotion and its intensity level. One reason is that people generally are more prompt to recognise exaggerated emotions in robots [108, 109]. Still, this relatively high intensity might impact how authentic the emotion is perceived. Even though these empirical works have started to investigate the role of the type of emotion and its intensity on people’s perception of robots, what motivated this thesis work was the lack of evidence to evaluate how children interact with social robots that display different levels of emotions.

**4.2.1 Design of the Stimuli**

Oosterhof and Todorov proposed a computational model to describe facial expressions [110]. They manipulated two dimensions (valence and dominance) to create a set of faces that elicited approach/avoidance and strength/weakness judgements. These faces represent happiness and anger at different intensity levels [111]. In this work, thus, happiness and anger were manipulated to signal approach and avoidance, as well as the intensity to suggest the strength of each emotion. Following the Action Units (AUs) framework for the measure of facial movements proposed by Ekman [112], the mouth and eyebrows regions of Furhat were manipulated to create a set of dynamic facial expressions of happiness and anger varying their intensity [113]. The in-built domain-specific language provided by Furhat in the Kotlin programming language was used to create the set of stimuli as shown in Figure 4.3. As such, the first two independent variables for Study 3 included *Emotion Type* with two levels (Happiness and Anger) and *Level of Intensity* with three levels (Low, Medium, and High).

\(^2\)https://furhatrobotics.com
Figure 4.3. Samples of stimuli projected onto the Furhat robot. Left, the valence dimension was manipulated to signal Happiness and Anger. The intensity dimension was manipulated to create three levels of intensity: low, medium, and high. Right, the gender likeness was manipulated to give the robot a female-like and male-like facial appearance. The dynamic facial expressions of emotions were used in the experiment reported in Paper

Moreover, several HRI studies have investigated how a robot’s perceived gender influences how people respond to it [114]. Findings suggest that male-like robots appear more persuasive than female-like robots [115], while robots with a female-like body shape are perceived as more trustworthy than robots with a male-like body shape [116]. Therefore, this study also explored whether applying a male or female facial texture to the mixed embodiment robot affects children’s perceptions of trust in and liking of the social robot Furhat. Gender likeness was the third independent variable of Study 2 with two levels: Female-like and Male-like. The two face textures used are depicted in Figure 4.3.

Validation of the Stimuli

All the stimuli were validated in a user study through Amazon Mechanical Turk (AMT). The objective of the validation study was to assess whether the type of emotion (happiness and anger) and the intensity level (low, medium, high) were perceived as intended in Figure 4.3 by the participants. The results obtained confirmed that happiness was correctly identified by most of the participants, while anger was most challenging to identify as it was sometimes confused with disgust. Concerning the intensity level, the results of the validation study confirmed that high levels of emotion are easier to recognise, followed by low and medium levels as the most challenging level to identify. Overall, the majority of participants identified the type of emotion and level of intensity accurately. Considering the human-level recognition rates, the set
of stimuli created was considered valid for the experimental user study with children presented in Paper IV.

4.2.2 Experimental Setup and Procedures
Data collection occurred for two of three days during a science fair for children in Uppsala, Sweden. Two children participated in the experiment simultaneously but were instructed not to talk to each other during the experiment. Each child rated two robots, a female-like and a male-like robot, varying the emotion and level of intensity. They were exposed to each stimulus for five seconds. A blanket covered each stimulus before and after the experiment. The experimenter took notes to collect information about the study and be able to exclude participants that did not meet the inclusion criteria at a later point (e.g., children that were exposed to the robot before). Additionally, the experimenter documented the children’s reactions to the robot when it was uncovered.

4.3 Study 4: Robot-related Factors, Human Likeness
Expanding on this thesis’s goal of understanding which robot-related factors in terms of behaviour and embodiment influence trust, this study sought to explore deeper into the role of human-like attributes of a robot and their impact on children’s trust and performance during the storytelling task. In Study 4, the robot’s human likeness was manipulated in terms of appearance, including visual and auditory cues and the robot’s verbally responsive behaviour.

4.3.1 Design of the Robot’s Appearance
Previous work in cHRI suggested that a robot’s appearance may influence children’s attitudes toward robots, such as mirroring behaviours of humanoid robots or eliciting more affection towards zoomorphic robots [117]. Beyond the morphology of social robots, human likeness has also impacted children’s perceptions of robots. Woods et al. found that children rated human-like robots as more aggressive and less friendly than machine-like robots [118]. However, a follow-up study found that the robots’ appearance with moderate levels of human likeness could be more beneficial for child-robot interaction than high levels of human likeness [119]. Moreover, there is evidence that auditory cues influence people’s trust in social robots and that a robot’s voice should be congruent with its behaviour [120, 121]. Furthermore, discrepancies between robot appearance and voice (alongside other human likeness cues) could adversely affect acceptance of social [122].

A set of visual and auditory stimuli was created by varying the degree of human likeness of the Furhat robot, ensuring a consistent and congruent
appearance-voice relationship. This approach aimed to get two validated robot versions—a human-like and a machine-like to be projected onto the Furhat robot—to investigate the effects of human-likeness, in terms of appearance and voice, on children’s trust and liking.

Visual Cues
The visual cues validation study aimed to select one human-like and one machine-like texture with clear facial cues to control the robot’s visual human likeness in the user study presented in Paper V. The set of stimuli was designed to prevent a specific gender and uncanniness. Six different faces were created for the child mask of the Furhat robot and validated in an online study involving 62 participants ($M = 41, F = 23$). The stimuli were rated regarding anthropomorphism, animacy, likeability and gender.

After statistical analysis, the two stimuli perceived as the most anthropomorphic ($W = 34.5, p.adj = 0.025, r = 0.61; M = 3.71, SD = 0.98, Mdn = 4.0$), and animate ($W = 24, p.adj = 0.023, r = 0.51; M = 3.89, SD = 0.77, Mdn = 4$), and the least anthropomorphic ($M = 3.15, SD = 1.04, Mdn = 3.25$) and animate ($M = 3.3, SD = 1.14, Mdn = 2.9$) were selected. Therefore, the two resulting face textures depicted in Figure 4.4 were chosen as the most human-like and machine-like.

Auditory Cues
The auditory cues pilot study aimed to select one human-like and one human-machine voice synthesiser with clear cues to control the robot’s auditory human likeness in the main experiment. The commercial Amazon Polly voices 3: Ivy, Justin, Russell, and Nicolle, were selected for the validation study. The prosodic features, such as pitch and rate, were modified to give the impression of a child’s voice congruent with the robot’s child-face mask. The most human-like and the most machine-like rated voices were used in the study presented in Paper V.

A total of 56 ($M = 35, F = 21$) participants rated all the auditory stimuli regarding anthropomorphism, animacy, likeability, gender, and age. After statistical analysis, the Amazon Polly voice “Justin”—pitch = medium, rate = 0.7—was perceived as the most anthropomorphic ($M = 3.54, SD = 0.87, Mdn = 2.4$), animate ($M = 3.65, SD = 0.86, Mdn = 3.6$), and likeable ($M = 3.94, SD = 0.88, Mdn = 4.0$), hence, it was selected as the most human-like voice. Concerning the most machine-like voice, the voice “Russell” was perceived as less anthropomorphic ($M = 2.70, SD = 1.12, Mdn = 2.8$), less animate ($M = 2.95, SD = 0.96, Mdn = 2.7$), and significantly less likeable ($M = 2.89, SD = 1.06, Mdn = 2.8$) than the other voices. It was also perceived as an adult voice ($M = 21.84, SD = 10.47$) rather than a child’s or teen’s voice. This voice was discarded to avoid eliciting feelings of uncanniness or

3https://docs.aws.amazon.com/polly/latest/dg/voicelist.html
being introduced as a confound. The voice “Ivy”—pitch = high, rate = 0.7)—was the second voice that was perceived as less anthropomorphic (M = 2.95, SD = 1.14) and was rated as a teen’s voice (M = 16.53, SD = 8.93). Therefore, it was chosen as the machine-like voice.

Finally, to get two robot versions that were congruent in terms of the perceived level of human likeness—in both visual and auditory cues, the resulting stimuli from the two validation studies were combined according to their levels of human likeness, resulting in human-like Furhat robot and a machine-like Furhat robot, as the first independent variable, Appearance, used to investigate the effect of human likeness on children’s trust in the user study presented in Paper V.

Figure 4.4. Description of the conditions used in Study 4 presented in Paper V. On the left, the independent variable Appearance with two levels: human-like and machine-like. On the right, examples of the independent variable Lexical Alignment with two levels: alignment and misalignment.

4.3.2 Design of the Robot’s Behaviour and Storytelling Scenario

The storytelling scenario designed in Study 2 (cf. Section 4.1) was also implemented in this study. However, the robot’s behaviour varied in two aspects. Firstly, results from Study 2 indicated that the robot’s behaviour should provide opportunities for turn-taking by offering back-channelling cues. Second, in this study, the robot acted more as a storyteller companion rather than an
active listener by providing ideas for the story and taking turns with the child. A set of robot ideas were employed based on the stories told by children in the first user study (Paper II and Paper III). As such, the robot’s behaviour matured as more information was gathered from the user studies with children. This method allowed adapting the storytelling game to a more collaborative setup facilitating story creation between the child and the robot.

To further explore the impact of human likeness on children’s trust, the second independent, *Lexical Alignment*, was introduced. This variable, representing the robot’s responsive verbal behaviour, had two levels: alignment and misalignment. The robot’s utterances were congruent with the graphical interface in the alignment condition. In contrast, in the misalignment condition, the robot’s utterances differed from the characters, objects, and scenarios presented in the graphical interface. Figure 4.4 illustrates how the conditions were implemented in Study 4.

4.3.3 Experimental Setup and Procedures

Data collection took place during the global COVID-19 pandemic. Two researchers conducted the user study in an international public school in Uppsala, Sweden. One researcher was responsible for guiding the children through the activity and administering pre-and post-test, while the other managed the technical setup and teleoperated the robot. The experimental setup involved the participant sitting on the side of a table, with the robot mounted on the other side, facing the child. A touchscreen was positioned on the table to display the storytelling activity’s interface (see Figure 4.5). Children were asked to tell a story to the robot using the elements displayed on the graphical interface. They were informed that the robot would help them tell the story by introducing some ideas, but they were the primary storyteller. After all the children had participated in the study, the researchers revealed that the robot was teleoperated in a plenary session and invited children to try controlling the robot.

4.4 Study 5: Repeated Interactions

Exploring the long-term effects of robot-related factors on children’s trust is crucial in educational robotics, as children are likely to interact with robots over extended periods of time to support their learning. Trust is a dynamic construct that may evolve over time as children become more familiar with the robot’s capabilities and limitations [5, 123]. Thus, investigating how trust develops in longer interactions can provide insights into the factors that contribute to the maintenance or decline of trust, which can inform the design of more effective and engaging robotic systems. Moreover, children’s percep-
Figure 4.5. Schematics of the experimental setup for Study 4, presented in Paper V. On the left, the participant and the robot are playing the game using the software displayed on a touchscreen. On the right, the experimenter is teleoperating the robot on the right using a control interface. A different area is dedicated to conducting pre- and post-tests.

...tions and expectations of a robot may change as they gain more experience with the system [101].

Studies exploring trust in repeated interactions can help identify potential shifts in children’s expectations and behaviours and determine whether the robot can adapt and maintain a positive relationship with the child. This study aimed to examine other factors, such as time, affect children’s trust dynamics and behaviour towards social robots, as well as the effect on verbal creativity. To achieve this goal, Study 5 was designed with Interactive Session as the independent variable with two levels, session 1 and session 2.

4.4.1 Design of the Scenario for Repeated Interactions

This study was conducted during the highest pick of the global COVID-19 pandemic. Therefore, the experiment needed to be adapted to an online setup.

Storytelling: Graphical Interface

A second version of the storytelling activity was developed to conduct online studies and sustain long-term interactions as described in the studies in Papers VI and VII. The graphical interface was created using PlayCanvas Web Game Engine⁴. The storytelling application included three topics (beach, farm, and rainforest) with two different scenes each. A set of nine characters and eight objects was available to help children elaborate on their story creation. The

⁴Web engine used for the online Storytelling activity: https://playcanvas.com
Figure 4.6. Samples of the storytelling graphical interface developed for the online study presented in Paper VI and Paper VII. Each story topic included two scenes, nine characters, and eight objects.

software allowed moving the characters and objects around the scenes and navigating through them using the mouse. Figure 4.6 illustrates an example of the graphical storytelling interface.

The Virtual Social Robot
The virtual version of the Furhat robot was used as the robotic agent for this study. At the time of the data collection, the “Anime” character was the closest texture in the virtual robot to the child version in the physical robot. To support repeated interactions, the robot’s verbal behaviours and robot’s ideas were modified in the second encounter, as shown in Table 4.3.

The study participants were Spanish speakers, and as the robot’s behaviours were initially developed in English (Study 2 and Study 4), the robot’s behaviours were translated into Spanish for Study 5.

4.4.2 Experimental Setup and Procedures
Data collection was conducted for two consecutive weeks and was entirely online using Zoom’s video conferencing tool. The local school teachers assigned an unused room exclusively for the study, where a computer with a camera and microphone was placed. Two teachers and two students from the last grade were responsible for the coordination and logistics at the school. Their tasks included taking each participant to the room, starting the video call, and
Table 4.3. Samples of the robot utterances during the storytelling activity presented in Paper VI and Paper VII. The robot utterances had variations from session 1 to session 2 to ensure consistency in each interactive session.

<table>
<thead>
<tr>
<th>Category</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question</td>
<td>“Hello, it’s nice to see you again”</td>
</tr>
<tr>
<td></td>
<td>“I had a lot of fun last time”</td>
</tr>
<tr>
<td>Guidance</td>
<td>“Do you want to play another storytelling game?”</td>
</tr>
<tr>
<td></td>
<td>“Do you remember what the game is about?”</td>
</tr>
<tr>
<td></td>
<td>“Mmmm, I have an idea!”</td>
</tr>
<tr>
<td>Story</td>
<td>“Let’s say that there was an evil alien destroying the world”</td>
</tr>
<tr>
<td>Ideas</td>
<td>“Let’s say that there was a magic hose that had very long legs”</td>
</tr>
</tbody>
</table>

launching the game’s graphical interface. See Figure 4.7 for the schematics of the experimental setup.

Each child played a total of two storytelling sessions with the virtual Furhat robot—one session per week. The procedure was the same for each interactive session: at the scheduled time, the child was guided to the experimental room, where they attended the video call alone. The experimenter explained the activity to the participants, guided them through the different stages, provided the questionnaires, and teleoperated the virtual robot. The storytelling activity was consistent with the one presented in previous studies. The experimenter turned off her camera to avoid participants getting distracted by her presence. Once the participants finished the experiment, the experimenter answered their questions and explained the functionality of the virtual robot.

Figure 4.7. Setup of the user Study 5 presented in Paper VI and Paper VII. The storytelling game had an online setup. The online setting included the “Anime” texture of the virtual Furhat robot, the Wizard of Oz interface, the graphical interface of the game, and the Zoom conference application.
5. Paper Contributions

5.1 Paper I A Meta-analysis on Children’s Trust in Social Robots

5.1.1 Contribution to Thesis

Paper I aimed to provide a more precise and accurate estimate of the true effect size of different factors on children’s trust in robots. This paper contributes to RQ1 by systematically combining and analysing existing empirical studies investigating trust in cHRI. This meta-analysis offers a robust definition of the multidimensional nature of children’s trust, encompassing social trust and competency trust. It identifies several factors influencing children’s trust in social robots and distinguishes between social trust and pro-social attitudes, such as liking and friendship. Lastly, the paper explores various methods employed to measure children’s trust and how the researchers interpreted those methods. In Paper I, the Ph.D. student collaborated with Rebecca Stower—Ph.D. student at Jacobs University at the time—on a 50% basis, and shared first co-authorship.

5.1.2 Background and Methodology

The current state of research makes determining children’s trust in social robots difficult due to two major issues. The first refers to differences in definitions and measurements, precisely the distinction between the various dimensions of trust as presented in Section 2.4.1. The second relates to inconsistent findings regarding the effects of robot behaviour and embodiment on trust described in Section 2.4.2. To fill these gaps, this study critically examines the current state of the art by conducting a meta-analysis to develop a comprehensive understanding of the role of trust in children’s relationships with social robots.

To accomplish this, four independent multivariate mixed-effects meta-regression models were employed for social trust, competency trust, and pro-social attitudes. To examine the true effect of different robot-related characteristics on children’s multidimensional trust, 52 effect sizes were extracted from 20 empirical studies in cHRI.

Data Sourcing

An initial pool of 414 papers was identified by searching the relevant work in multidisciplinary databases, including Web of Science, Scopus, IEEE Xplore...
and PsycINFO (the last search was conducted in January 2020 with the identification of 351 papers), and 63 papers through additional sources.

The screening process consisted of two steps. First, titles and abstracts of all retrieved papers were screened, and irrelevant papers were discarded, yielding 100 relevant papers. Following a full-text screening to ensure eligibility and refine inclusion criteria, 36 papers were chosen. Second, papers were categorised as suitable for qualitative or quantitative evaluation. Studies without manipulation or independent variables were retained for qualitative analyses only, as well as studies which did not explicitly measure trust or measured trust only as part of a broader construct, such as engagement, anthropomorphism, or perceived social other, or papers containing only observations from teachers or parents rather than direct measurements from the children themselves. Following this approach, $k = 20$ papers were retained for quantitative analysis, and metadata, study information, dependent and independent variables, and study design were extracted from these papers.

**Dependent Variables**

In line with existing empirical work and for the purpose of this work, two dimensions of trust are defined: 

- **Social trust**, as a belief that [the robot] will keep their word or promises following the definitions in [63, 64];
- **Competency trust**, as the perceived competence or reliability of [the robot], as stated in [124].

To investigate whether trust in cHRI follows a multidimensional nature, trust measures were classified into three categories: (1) Social trust, such as self-disclosure and secret-keeping, (2) Competency trust, such as endorsing labels, following instructions, and self-report measures; and (3) Pro-social attitudes, such as liking and friendship. Figure 5.1 shows the framework used to define the multidimensional nature of trust and pro-social attitudes constructs that may overlap with social trust. These definitions were consistently applied throughout all the studies in this thesis.

**Independent Variables**

To run the meta-analytic models, the following data were retrieved along seven dimensions or moderators: (1) The age range and mean of the study’s participants, (2) the structure of the interaction (such as a game, learning task or interview) as the interaction type, (3) the interaction length in minutes, (4) the robot type used in the study was categorised as humanoid or non-humanoid, (5) the robot operation, which can be fully automated, partially automated, or teleoperated, (6) the robot-related factors such as behaviour, embodiment, and error, and (7) the type of measure, whether the data were collected using subjective or objective techniques. To better understand the precise effects of robot-related factors on social and competency trust, the data extracted for moderators was divided into two categories, as described in [2]. As a result, more social conditions (embodiment, behaviour or errors) were part of the
5.1.3 Results

The 20 studies that were investigated yielded a total of 52 effect sizes, with 20 effects for social trust, 19 effects for competency trust, and 13 effects for pro-social attitudes. Children’s ages generally varied from 3 to 17 ($M = 8.25, SD = 2.81$). The length of interactions ranged between 4 and 60 minutes ($Mdn = 17$).

The analysis consisted of four multivariate mixed-effects meta-regression models for social trust and competency trust first individually and then combined, examining the effects of the seven moderators on each. The trust and pro-social measures were the dependent variables (i.e., social trust, competency trust, and liking), and the moderators acted as independent variables.

Social Trust

A non-significant effect exists between study heterogeneity in effect sizes, $Q(13) = 14.97, p = .309, I^2 = 20.99\%, \tau^2 = 0.023$, indicating a low between-study variation in effect sizes. However, this result should be interpreted cautiously as the included studies had large confidence intervals, as shown in Figure 5.2.
The overall meta-analytic model was non-significant, $Z = 1.768, p = .077$, 95% CI = $[-0.02, 0.38]$, and adding moderators did not account for any additional variance. However, there was a trend in the type of measure suggesting that objective measures positively affected social trust for human-like features ($p = .080$). A post hoc power analysis was then performed. For between-groups studies with average $N = 34$, observed power was 11%, and for within-groups studies (average $N = 19$), it was again 11%, indicating that these studies were significantly underpowered. Using the extracted average effect size of $d = 0.18$, the number of participants that are required to detect a significant effect with 80% power is 491 per condition for between-groups studies and 247 per condition for within-groups studies.

### Competency Trust

The overall test for heterogeneity was significant, $Q(11) = 174.70, p \leq .001$, $I^2 = 79.14\%$, $\tau^2 = 0.212$, which is not surprising given the large amount of variation in study designs, methods, and samples found when extracting the data. Furthermore, considerable heterogeneity shows that moderators may impact how robot-related elements affect competency trust [125].

The overall meta-analytic model for competency trust was non-significant, $Z = 1.368, p = .171$, 95% CI = $[-0.07, 0.41]$. However, after accounting for the effect of moderators, there was a significant effect of interaction type and robot-related factors ($p < .001$). Regarding interaction type, only chil-
Figure 5.3. Forest plot of Competency Trust effects. The circle size represents the effect size weight, and the length of the whiskers shows confidence intervals. The diamond reflects the overall effect size.

Children who interacted with the robot in a game context showed a significant effect of human-like attributes on competency trust ($p = .031$). Regarding robot-related factors, children who interacted with a robot that made an error significantly increased competency trust compared to those who interacted with a non-faulty robot ($p = .012$).

Concerning the post hoc power analysis, the observed power was 11% and 10% based on the current average sample sizes of $N = 40$ and $N = 17$, for between and within groups, respectively. To reach 80% power with the identified average effect size of $d = 0.16$, 558 participants are needed per condition for between-groups studies and 281 for within-groups.

Social and Competency Trust

The third multivariate mixed-effects regression model integrated social and competency trust as outcomes. The between-study heterogeneity in all cases was low to moderate, yet still significant, $Q(23) = 53.42$, $p \leq .001$, $I^2 = 48.04\%$, $\tau^2 = 0.042$.

The overall meta-analytic effect size was significant for competency trust, $Z = -2.655$, $p = .008$, 95% CI = $[-0.44, -0.07]$, but not for social trust, $Z = 1.560$, $p = .119$, 95% CI = $[-0.05, 0.40]$. Younger children demonstrated greater competency trust in the robot than the older ones ($p = .006$). The type of interaction with the robot was again significant ($p = .004$). However, the direction differed from the model focusing solely on competency
trust, indicating that when children engaged with the robot in a game, human-like attributes had a negative impact on competency trust. The interaction length was non-significant at the $p < .05$ level but hinted at a trend in which shorter interactions resulted in higher competency trust ($p = .053$). The robot operation moderator was significant ($p = .009$), with experiments involving teleoperated robots showing a negative effect of human-like features on trust. Additionally, when considering the manipulation of robot-related factors, the robot’s behaviour influenced trust so that more human-like behaviour led to significantly lower competency trust ($p = .005$). Lastly, the significant effect of the type of measure concerning subjective measures also had a reverse direction, suggesting these measures elicited a negative effect on competency trust for human-like attributes ($p = .006$).

Regarding the observed power, the result was 12% for between-groups studies, with an average $N = 38$, and 11% for within groups, with an average $N = 18$. Conversely, to detect an effect of ($d = 0.17$) as identified in the model, 491 participants are required per condition for a between-group study and 247 per condition for within-group studies.

**Social Trust and Liking**

In the final meta-analysis, studies on social trust were combined with those assessing liking and/or friendship. The $Q$-test for heterogeneity was significant, $Q(22) = 84.24$, $p = < .001$, $I^2 = 74.63\%$, $\tau^2 = 0.216$, suggesting that differences in study-specific moderators may account for differences in effect sizes between studies.

The overall meta-analytic effect size was significant for liking ($Z = -2.326$, $p = .02$, 95% CI = $[-0.99, -0.08]$) but not for social trust ($Z$-value = 0.961, $p = .336$, 95% CI = $[-0.19, 0.54]$). Introducing moderators into the model accounted for a significant additional variance in liking. Age was a significant factor, with younger children showing a greater liking for the robots, $Z = -3.246$, $p < .001$. The type of interaction was significant, with studies involving children playing games with robots showing a negative effect of human-like features on liking, $Z = -2.180$, $p < .029$. Interaction length was also significant, with shorter interactions leading to increased liking ($Z$-value = $-2.507$, $p = .012$). For the robot operation, the model for liking was significant for teleoperated robots ($Z$-value = $-2.533$, $p = .011$) and autonomous robots ($Z$-value = $-2.331$, $p = .02$), revealing a negative effect of human-like attributes on liking in both cases. Studies comparing a robot and a human showed a significantly higher preference for the robot ($Z$-value = $-3.370$, $p < .001$). Similarly, a more robot-like embodiment was also favoured in studies that manipulated embodiment ($Z$-value = $-3.301$, $p < .001$). Finally, concerning the type of measure, objective measures had a reverse direction, suggesting that more human-like features led to a lower liking for studies where these kinds of measures were used ($Z$-value = $-1.025$, $p = .044$).
Table 5.1. Summary of the results for the four meta-analytic models. For the main effects, significance is highlighted in bold. Only significant moderators with a $p$-value below .05 are presented in this table. † indicates a trend towards significance. The sign within the parenthesis shows whether the effect was positive (+) or negative (-) on the trust outcome.

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Social Trust</td>
<td>Competency Trust</td>
<td>Social Trust</td>
<td>Competency Trust</td>
</tr>
<tr>
<td><strong>Main effect</strong></td>
<td>$p = .077^{†}$</td>
<td>$p = .171$</td>
<td>$p = .119$</td>
<td>$p = .008$</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td>Older (-)</td>
<td>Older (-)</td>
<td>Older (-)</td>
<td>Older (-)</td>
</tr>
<tr>
<td><strong>Interaction type</strong></td>
<td>Game (+)</td>
<td>Game (-)</td>
<td>Game (-)</td>
<td>Interview (-)</td>
</tr>
<tr>
<td><strong>Interaction length</strong></td>
<td>Shorter† (+)</td>
<td>Shorter (+)</td>
<td>Shorter (+)</td>
<td></td>
</tr>
<tr>
<td><strong>Robot type</strong></td>
<td>Humanoid (-)</td>
<td>Robot-like (+)</td>
<td>Robot-like (+)</td>
<td></td>
</tr>
<tr>
<td><strong>Robot-related factors</strong></td>
<td>Error (+)</td>
<td>Behaviour (-)</td>
<td>Behaviour (-)</td>
<td></td>
</tr>
<tr>
<td><strong>Robot operation</strong></td>
<td>WoZ (-)</td>
<td>WoZ (-)</td>
<td>Autonomous (-)</td>
<td></td>
</tr>
<tr>
<td><strong>Type of measure</strong></td>
<td>Objective† (+)</td>
<td>Subjective (-)</td>
<td>Objective (-)</td>
<td></td>
</tr>
</tbody>
</table>

The observed power was 49% for between-group studies with an average $N = 27$, and 69% for within-group studies with an average $N = 23$. While this is an improvement compared to previous models, it is still below the desired 80% power threshold. To achieve 80% power with a moderate effect size of $d = 0.54$, 55 participants are required per condition for between-group studies and 29 per condition for within-group studies. The number of needed participants is lower than in earlier models due to the larger overall effect size [126].

5.1.4 Summary

The findings above indicate a negative influence of human-like features on competency trust. This implies that robots with more human-like behaviour or appearance adversely affect the competency trust that children place in them. This observation is crucial as it challenges the assumption that increasing human-like features in robots would necessarily lead to higher levels of trust.

Furthermore, the meta-analytic models revealed no impact on social trust, which may be attributed to the large variability among studies assessing social trust. This variability could stem from differences in experimental designs, instruments used to capture trust, robot-related features, or participant populations, making it difficult to draw general conclusions about the effect of the moderators on social trust.
Table 5.1 provides an overview of the significant effects of the moderators on the four meta-analytic models. This summary provides insights into how specific factors, such as the dimension of trust evaluated and the moderators manipulated, influence trust in child-robot interaction. Understanding these relationships could contribute to designing and developing social robots that foster trust and rapport with children, especially in contexts where trust is critical for successful collaboration and learning.

5.2 **Paper II** Promoting Children’s Verbal Creativity using a Robot

5.2.1 Contribution to Thesis

This paper contributes to **RQ2** and provides empirical evidence for designing and implementing a storytelling learning task to facilitate learning with a social robot. Specifically, it demonstrates how emotion-driven strategies incorporated into a social robot can promote higher verbal creativity in children. This research measures verbal creativity through a collection of objective measures, assesses the emergence of the robot’s verbal behaviour during the interaction, and reflects on its role as a learning companion.

In Paper II, the Ph.D. student collaborated with Maha Elgarf—Ph.D. student at KTH, Sweden, at the time—on a 50% basis, and shared first co-authorship.

5.2.2 Background and Methodology

Prior research has proposed that the way people regulate their emotions could contribute to enhanced creativity [95, 127]. The RFT outlines one method of emotional regulation through two self-regulatory focus strategies [99]. Promotion focus is associated with positive outcomes and feelings of joy and excitement when goals are met. In contrast, prevention focus is linked to the desire for security and feelings of relief upon accomplishing goals [128]. Although creativity with robots has been examined in cHRI, there is a scarcity of collaborative situations that utilise the regulatory focus emotion-driven framework to promote creativity among children. This study evaluates whether a cooperative activity can evoke emotions related to promotion and prevention focuses paradigms during a goal-oriented collaborative task with a social robot and its effects on verbal creativity.

**Experimental Design**

This study aimed to develop a storytelling scenario that serves as a collaborative learning task with a social robot to promote verbal creativity as the learning outcome. To accomplish this, this study compared two regulatory
focus techniques devised to evoke emotions in children by using the Priming Activity outlined in Section 4.1.1. The study followed a mixed design, where pre- and post-storytelling activities were within-subjects factors, and promotion and prevention conditions were between-subjects factors.

In the experimental investigation, 69 children aged between 7 and 9 years old ($M = 7.58, SD = 0.58$) participated in the study. The children were English speakers and attended second and third grade at two private international schools where the study took place. Participants were randomly allocated to either promotion or prevention conditions. Following data exclusion, data from 32 children (17 girls, 15 boys) in the promotion condition and 29 children (14 girls, 15 boys) in the prevention condition were used for analysing the results. Figure 5.4 presents snapshots of children interacting with the social robot EMYS. Please refer to Section 4.1 for details about the experimental setup.

![Fig 5.4](image)

*Figure 5.4. Children playing the (a) priming activity and (b) storytelling activity, together with the social robot EMYS.*

**Validation of the Priming Activity**

The first step to evaluate the impact of the RFT intervention on children’s verbal creativity is to determine whether the priming activity successfully induced the regulatory focus-related emotions in children. Children’s behaviour was analysed for emotional induction, with facial expressions from frontal videos analysed using Affectiva$^1$ software, and attention and engagement-related behaviours annotated for statistical analysis. The focus is on joy and fear, corresponding to promotion and prevention strategies. Wilcoxon signed-rank non-parametric tests showed that children in the promotion condition displayed significantly more smiles ($W = 199, p = 0.013, M = 9.45, SD = 12.92$) and

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$^1$Affectiva Software: [https://www.affectiva.com/](https://www.affectiva.com/)
Joyful expressions ($W = 216, p = 0.03, M = 7.52, SD = 12.04$) than in the prevention condition, indicating the intervention’s success. These results, derived from the analysis and procedures for emotional detection from the same study and published in [129], serve as a confirmatory analysis of the priming activity’s success, which is crucial for the studies presented in Paper II and Paper III.

### Creativity Measures

Various methods have been used to assess creativity in children. This work focuses on verbal creativity, which is typically measured using four criteria [130, 131, 132]: (1) **Fluency**: the number of ideas generated during the creative process, (2) **Flexibility**: refers to the various distinct aspects that the generated ideas cover, (3) **Elaboration**: denotes the number of elaborated details in the ideas produced. 4) **Originality**: refers to the novel and surprising element introduced by the ideas. Based on these criteria, a set of objective measures were designed to evaluate the effects of RFT on the creative process:

- **Fluency** — The total number of story elements verbally expressed by a participant during storytelling. There was no distinction between action, scenario, objects, affective expression, and character.

- **Flexibility** — Ideas related to the plot encompassing five categories of story elements: characters, actions, scenarios, objects, and affective expressions.

- **Elaboration** — The total time children spoke corresponds to the story’s length when considering the first and last story elements.

- **Originality** — The presence of novel ideas that are unexpected or unusual. Each story idea from the category **Fluency** was assigned a level of originality on a 1-to-3 scale: “1” represents limited or very short clauses related to objects already present in the application or traditional story plot. “2” is given to clauses that demonstrate creative power when using objects already present in the application and clauses that are surprising but have a traditional plot background. “3” is given to highly creative and invested clauses, such as new story elements beyond the existing ones in the application or surprising clauses.

### Inter-rater Agreement

Behavioural coding analysis was conducted using the ELAN$^2$ software, developed by the Max Planck Institute for Psycholinguistics [133]. The measures for verbal creativity were validated by adhering to standard practice for inter-rater agreements. Two coders randomly double-coded 25% of the video data according to these creativity measures. Cohen’s Kappa value was employed to evaluate the agreement between the two coders. After the analysis, the statistical measure ranged between 0.75 and 0.96 ($M = 0.89$), indicating high agreement between the two coders.

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$^2$ELAN Software [https://archive.mpi.nl/tla/elan](https://archive.mpi.nl/tla/elan)
5.2.3 Results

RFT Design and Children’s Creativity

Verbal creativity was assessed by analysing the data according to the creativity measures discussed in Section 5.2.2. The dependent variables were fluency, flexibility, elaboration, and originality. Log transformation was applied to normalise the data [134]. A mixed ANOVA parametric test for each dependent variable was implemented with “promotion” and “prevention” as between-subject factors, and “pre-test” and “post-test” as within-subject factors. Pairwise paired t-tests with Bonferroni correction were used to explore the effects of the within-subject factor (type of test) on the dependent variable in the different conditions (promotion vs prevention).

Fluency:
The type of test (pre- vs post-test) had a significant effect on fluency ($p = .016, \eta^2 = 0.011$). Post hoc analyses revealed that, in the promotion condition, children showed higher fluency of ideas in the post-test compared to the pre-test ($p.adj = .032, d = 0.341$). However, the same effect was not observed in the prevention condition, as shown in Figure 5.5a.

Flexibility:
This variable was measured as the frequency of the children’s ideas belonging to the five different categories. The ANOVA test results indicated a significant effect of the type of test on both frequency of characters ($p = .003, \eta^2 = 0.015$) and frequency of actions ($p = .002, \eta^2 = 0.023$). Post hoc analysis showed that the frequency of characters and frequency of actions were significantly higher in the post-test than in the pre-test in both the promotion ($p.adj = .027, d = 0.413$ and $p.adj = .044, d = 0.433$, respectively) and prevention conditions ($p.adj = .041$ and $p.adj = .018$, respectively).
Originality: A significant effect of the type of test was found on the average originality ($p = .039$, $\eta^2 = 0.017$) and the frequency of the ideas with a high level of originality ($p = .033$, $\eta^2 = 0.014$). The administered t-test showed that in the promotion condition, the average originality was significantly higher in the post-test compared to the pre-test ($p_{adj} = .041$, $d = 0.289$). Furthermore, post hoc analysis revealed that in the prevention condition, the frequency of originality at the high level was significantly higher in the post-test than in the pre-test ($p_{adj} = .002$, $d = 0.454$), as shown in Figure 5.5b.

Elaboration: This measure was examined as the total duration of the stories narrated by each child. The mixed ANOVA test revealed no significant effect of any of the independent variables on elaboration.

5.2.4 Summary
Overall, the results demonstrated that high levels of Fluency, Flexibility, and Originality were observed in both prevention and promotion conditions during the post-test, suggesting that priming influenced the children’s creative abilities. Notably, Fluency and average Originality were higher in the post-test than in the pre-test for the promotion condition. A significant finding is that the post-test in the prevention condition exhibited more highly original ideas than the pre-test.

5.3 Paper III How Regulatory Focus Design Affects Children’s Trust in a Social Robot
5.3.1 Contribution to Thesis
This paper contributes to RQ2 by providing empirical evidence regarding the influence of emotion-driven non-verbal and verbal robot behaviours on children’s trust and their willingness to accept robot suggestions. Notably, the key finding suggests that subjective and objective measures may not always show a correlation, even when designed to capture the same trust outcome.

5.3.2 Background and Methodology
The experimental design, procedures, and validation of the priming activity of this paper correspond to Study 2. Therefore, they have already been discussed in Sections 4.1 and 5.2.2.
Trust and Liking Measures
This paper examined children’s social trust, competency trust, and liking towards the robot by using subjective and objective measures.

Questionnaires were employed as subjective measures to assess children’s perceptions of trustworthiness in the social robot. Two distinct scales were used to investigate social trust and competency trust. The first scale, inspired by the instruments measuring children’s interpersonal trust as indicated in [48], mirrors the items studied in social trust in Paper I (i.e., secret-keeping and honesty). Regarding competency trust, an adapted scale was implemented by utilising the Trust and Perceived Usefulness items from the Unified Theory of Acceptance and Use of Technology (UTAUT) [135].

In relation to objective measures, Madsen and Gregor defined trust as the degree to which a user has confidence in and is willing to act based on a system’s recommendations, actions, and decisions [136]. This suggests that children’s competency trust in social robots may be captured by their willingness to follow their advice [31] and rely on the robot’s behaviours to make decisions [107]. Therefore, to determine whether children accept or reject the robot’s suggestions and requests, a set of five children’s behaviours were used to capture competency trust in the robot as follows:

- **Compliance-Suggestions** — The participant follows the robot’s suggestion.
- **Resistance-Suggestions** — The participant rejects the robot’s suggestion.
- **Compliance-Request** — The participant complies with the robot’s request.
- **Resistance-Request** — The participant refuses the robot’s request.
- **Free-Action** — The participant is free to take action. It means that the robot does not give suggestion or makes a request.

Validation Objective Measures
Two coders randomly annotated 20% of the video data to validate the objective measures outlined in the previous section. Data extraction focused exclusively on the priming activity. An inter-rater reliability analysis employing Cohen’s Kappa was conducted to evaluate coder consistency. The average degree of inter-rater agreement for all items reached 0.71, falling within the substantial strength for agreement range [137].

5.3.3 Results

Subjective Measures
The data deviated from normal. Therefore, non-parametric Mann-Whitney tests were employed for statistical analysis, with “promotion” and “prevention” as between-subjects factors.

Social trust was assessed regarding secret sharing. Findings revealed a non-significant effect of regulatory focus design on social trust ($U(N_{prom} = 28, N_{prev} = 27) = 417, z = .68, p = .496, r = .09)$.
Four items were considered to assess children’s competency trust: help, imagination, good advice, and adherence to suggestions. Non-parametric tests revealed no significant effects on competency trust.

Pro-social attitudes were assessed by evaluating children’s perceived likeability and friendliness of the robot. A significant effect of the condition on likeability ($U(N_{prom} = 29, N_{prev} = 27) = 482, z = -2.32, p = .020, r = -.31$), showing that children found the prevention-focused robot ($M = 4.93, SD = 0.38$) more likeable than the promotion-focused robot ($M = 4.66, SD = 0.67$). However, no significant effect was detected for Friendliness ($U(N_{prom} = 28, N_{prev} = 27) = 406, z = .87, p = .383, r = .12$).

**Objective Measures**

Children’s competency trust was evaluated by analysing their behavioural data concerning accepting or rejecting the robot’s advice and requests. Since the data did not follow a normal distribution, non-parametric tests were employed. The analysis did not reveal any significant effect of the conditions on any of the dependent variables, as shown in Figure 5.6.

![Figure 5.6. Effect of Regulatory Focus Design on objective measures of trust. (a) Percentage of robot suggestions accepted by children. (b) Percentage of robot suggestions rejected by children. (c) Free actions per condition during the Priming Activity. There were non-significant differences between conditions.](image-url)
Correlations between Subjective and Objective Measures
A Spearman’s rank correlation analysis was conducted to explore the relationship between subjective and objective measures. Results showed that the subjective measure for competency trust, “Helpfulness”, was significantly negatively correlated with the acceptance of the robot’s suggestions ($r = -0.39$, $p < .05$) and significantly positively correlated with the rejection of the robot’s suggestions ($r = 0.43$, $p < .05$). No further significant correlations were identified.

5.3.4 Summary
The findings indicate that the prevention focus strategy evokes higher pro-social attitudes regarding liking. Interestingly, the perceived helpfulness of the robot was negatively correlated with children’s willingness to accept the robot’s suggestions. The discrepancy between objective and subjective measures implies that instruments used to measure children’s trust in social robots should be validated and tested to ensure they accurately capture the intended outcome and avoid potential confounds.

5.4 Paper IV The Effects of Robot’s Facial Expressions
5.4.1 Contribution to Thesis
This paper contributes to RQ3 by providing empirical evidence on how robot-related factors impact children’s trust in robots. Specifically, this study investigates the influence of non-verbal behaviour, focusing on facial expressions of emotions during initial encounters. The main findings suggest that the robot’s trustworthiness is mediated by children’s first impressions of the robot’s perceived likeability and competency. Interestingly, lower levels of emotions are found to be more likeable, which may indicate that they were perceived as more authentic than higher levels of emotions.

5.4.2 Background and Methodology
The first impression provides insights into whether an individual can be trusted or not [111]. One of the robot-related features associated with social acceptance is the robot’s capability to convey emotions through body gestures or facial cues [64, 69]. Consequently, facial expressions of emotions have been proved to influence children’s judgments of trust, likeability, and attitudes towards robotic systems [69]. Therefore, facial expressions of emotions (happiness and anger) and their intensity (low, medium, high) were used as non-verbal robot behaviours to examine children’s perceptions of trust in robots during first encounters. Additionally, the robot’s appearance was manipulated
in terms of gender likeness (female-like and male-like) to investigate the effects of this manipulation on children’s perceptions of the robot. A set of 12 stimuli were designed to be projected onto the Furhat robot (further details about the materials can be found in Section 4.2).

Experimental Design
The study had three dependent variables—Emotion Type (Happiness and Anger), Intensity Level (High, Medium, and Low), and Gender (Female-like and Male-like). A total of 129 children aged between 9 and 14 years ($M = 11.29, SD = 0.85$) participated in the study and were randomly assigned to one of the six conditions. Each child was exposed to two stimuli for 5 seconds each, and asked to rate each robot in terms of trustworthiness, likeability, and competence.

Measures
Subjective measures were employed to evaluate children’s perceived likeability, competency, and trustworthiness of the robot. A scale adapted from the Children’s Interpersonal Trust Scale [48], as well as the Trust and Perceived Usefulness items from the UTAUT [135], were implemented. Additionally, a modified version of the GodSpeed questionnaire [138] was adapted to assess children’s liking of the robot.

5.4.3 Results
The study followed a mixed design, a 2X2X3 MANOVA—with Robot Gender as the within-subjects independent variable and Emotion Type and Intensity Level as between-subjects independent variables—was employed for the statistical analysis. All $p$-values of the post hoc analyses were adjusted using Bonferroni correction.

Effects of Emotion Type
The MANOVA results revealed a significant main effect of Emotion Type on the dependent variables ($F(8,191) = 2.869, p = .005$). Post hoc analysis indicated that children perceived the robot as more likeable in terms of appearance ($p = .001$) when it expressed happiness ($M = 3.38, SD = 1.01$) rather than anger ($M = 2.89, SD = 1.14$), and in terms of friendliness ($p = .023$) when it displayed happiness ($M = 3.36, SD = 1.04$) instead of anger ($M = 2.98, SD = 1.21$). Furthermore, the robot was deemed significantly more competent in terms of smartness ($p = .002$) when it exhibited happiness ($M = 4.12, SD = 0.95$) as opposed to anger ($M = 3.64, SD = 1.25$). However, Emotion Type had no significant effects on trustworthiness.
Effect of Intensity Level
A significant main effect of the Intensity level \((F(40,935) = 1.525, p = .021)\) was found on the dependent variables. Post hoc tests revealed that children rated the robot as more likeable in terms of appearance when it expressed low happiness \((M = 3.65, SD = 0.71)\) instead of high anger \((M = 2.76, SD = 1.4, p = .007)\) or low anger \((M = 2.92, SD = 0.98, p = .037)\). Furthermore, when the robot displayed low happiness \((M = 3.68, SD = 0.91)\) compared to medium happiness \((M = 2.73, SD = 1.04, p = .011)\) or high anger \((M = 2.67, SD = 1.59, p = .003)\), it was perceived as more likeable in terms of friendliness. In terms of competence, the robot was considered smarter when it expressed high happiness \((M = 4.36, SD = 0.82)\) as opposed to high anger \((M = 3.48, SD = 1.17, p = .038)\). A non-significant effect of Intensity Level on trustworthiness perception was found.

Effect of Gender Likeness
Results revealed a non-significant main effect of robot Gender \((F(8,183) = 1.275, p = .259)\) and no significant interaction effect between robot Gender and Emotion Type \((F(8,191) = 1.252, p = .271)\) on the dependent variables. However, a significant interaction effect between robot Gender and Intensity Level was observed \((F(40,935) = 1.453, p = .036)\). The interaction effect showed that the male-like robot was rated as more likeable in terms of appearance when it expressed high anger \((M = 3.62, SD = 1.4)\) rather than medium anger \((M = 2.89, SD = 0.87, p = .037)\), and when it expressed low happiness \((M = 3.75, SD = 0.57)\) instead of medium anger \((M = 2.89, SD = 0.87, p = .015)\) or low anger \((M = 3, SD = 1, p = .037)\). In contrast, the female-like robot was rated as less likeable in terms of appearance when it expressed high anger \((M = 1.94, SD = 0.89)\) instead of medium anger \((M = 3.15, SD = 1.14, p = .002)\), low anger \((M = 2.85, SD = 0.98, p = .008)\), high happiness \((M = 3.55, SD = 1.03, p < .001)\), medium happiness \((M = 2.88, SD = 1.2, p = .010)\), or low happiness \((M = 3.57, SD = 0.81, p < .001)\); also, when the robot displayed low anger \((p = .026)\) or medium happiness \((p = .042)\) instead of low happiness.

Exploratory Regression Analyses
Four regression analyses examined whether trustworthiness was mediated by likeability and competency. Results revealed that both friendliness \((\beta = .236, t(202) = 3.223, p = .001)\) and smartness \((\beta = .320, t(202) = 4.543, p < .001)\) were predictors of whether the robot was perceived as capable of keeping secrets, indicating pro-social attitudes as a predictor of social trust. Helpfulness was found to be a predictor of whether the robot was perceived as a truth-teller \((\beta = .203, t(205) = 3.108, p = .002)\), as capable of influence others \((\beta = .452, t(203) = 6.351, p < .001)\), and as reliable \((\beta = .290, t(202) = 4.147, p < .001)\). Furthermore, smartness \((\beta = .426, t(205) = 6.425, p < .001)\) was a predictor of whether the robot was perceived as a truth-teller. These findings
Figure 5.7. Exploratory regression analyses. Competency and Pro-social attitudes as predictors of trust in first encounters with social robots. Significant items are highlighted in colour. This study is presented in Paper IV.

suggest that trust has a competency trust dimension, which can be assessed by the perceived competence of the robot. Figure 5.7 summarises the regression analysis results.

5.4.4 Summary
The findings of this study demonstrate that children can form a trait inference based on the robot’s emotion within just a few seconds. Emotion type, emotion intensity, and gender likeness did not directly influence trust; however, the perception of the robot’s likeability and competence were facilitators for judging trustworthiness.

5.5 Paper V Robot’s Human-likeness and Lexical Alignment
5.5.1 Contribution to Thesis
This paper contributes to RQ3 by providing empirical evidence concerning the impact of varying levels of the human likeness of a robot, in terms of both appearance and behaviour, on children’s perception of and their behaviour towards the social robot. According to the objective measures employed in this paper, it was found that low levels of human likeness positively impact both social trust and competency trust when children engage with a social robot in a collaborative storytelling task. Intriguingly, these effects were not observed when relying on subjective measures. This discrepancy may suggest that subjective measures should be used cautiously with children, particularly when capturing complex constructs such as trust, as they might not accurately reflect children’s experiences and perceptions.
5.5.2 Background and Methodology

The physical appearance of a robot influences the user’s perceptions of trustworthiness [139]. A user study by [117] found that children who interacted with a humanoid NAO robot were more motivated to imitate the robot’s behaviour (e.g., waving, saying hello). In contrast, the zoomorphic Pleo robot evoked more affective behaviours, such as offering affection. Another study investigated how the robot’s appearance influences children’s perceptions of robots’ intentions and capabilities [118]. Results indicated that children rated human-like robots as aggressive and machine-like as friendly when assessing different robot appearances. A follow-up study that used videos of humanoid robots found that the level of human likeness affects children’s liking of the robots, suggesting that robots with a moderately human-like appearance are preferable to those with a highly human-like appearance [119]. Consequently, the way in which a robot’s human likeness is manipulated can help prevent adverse effects of human-like features on children’s trust in robots, as observed in Paper I.

A robot’s human likeness regarding verbal and non-verbal behaviours can also be studied. Wigdor et al. investigated the robot’s responsiveness as a human-like communicative behaviour [140]. Responsiveness is defined as “the proportion of responses related in content to the preceding behaviours of others” [141]. It describes how partners appropriately attend to and support each other’s needs [142] and is associated with developing intimacy in interpersonal relationships [143]. Storytelling allows for investigating the effect of the robot’s responsiveness through verbal and non-verbal communication. To facilitate communication during the storytelling, speakers should interactively align at different levels by adapting and re-using each other’s language patterns during an interaction [144, 145]. This kind of behavioural alignment influences rapport and learning [146].

Alignment can occur in various ways, including mirroring others’ affect, posture, speech patterns, and gestures [147, 148]. Lexical alignment mimics others’ speech patterns and has been studied in conversations with artificial agents [149]. In contrast, speech entrainment, which involves mimicking vocal features like speaking rate, pitch, and volume, has been explored in repeated encounters between children and social robots [146]. The learning storytelling task used in this thesis enables two-way lexical alignment between the child and the robot. In other words, the child and the robot can produce verbal responses matching their partner’s words.

The study investigates how different levels of human likeness impact children’s trust in and behaviour towards a storyteller robot. The human likeness is manipulated in terms of appearance and responsive behaviour, with an emphasis on evaluating the effects of this manipulation on children’s lexical alignment with the robot’s verbal behaviours and their perceptions of the robot as a trustworthy storytelling companion.
Experimental Design
A 2X2 user study was designed with four conditions to investigate the effects of human likeness on a robot’s appearance and behaviour. The first independent variable, concerning the robot Persona, was the robot’s appearance with two levels of human likeness: machine-like and human-like. The visual and voice cues of the Furhat robot were manipulated to design the two versions of the robot as discussed in Section 4.3.1. The second independent variable was the robot’s lexical alignment with two levels: alignment and non-alignment. This variable manipulated the robot’s verbal behaviour to match the two conditions described in Section 4.3.2.

A total of 52 children from ages 7 to 10 (M = 8.22, SD = 0.99) participated in the experimental study. An equal number of participants were assigned randomly to each of the four conditions. Participants were first- to third-year students at a local international school. Children played the storytelling game with the Furhat robot using the storytelling software displayed on a touch screen between the child and the robot, as depicted in Figure 5.8. Children did not have a time limit to tell their stories. Once the activity was finalised, they were told that the robot was teleoperated.

![Human-like Robot](image1.png) ![Machine-like Robot](image2.png)

*Figure 5.8. Children playing the storytelling game with the (a) human-like and (b) machine-like Furhat robots.*

Measures
Several objective and subjective measures were employed in this study to evaluate (1) perceived human likeness, (2) liking, (3) social trust, and (4) competency trust, as described below:

**Likeability** —Children’s interpersonal trust could be associated with prosocial attitudes such as liking and friendship [48]. A modified version of the
GodSpeed questionnaire [138] was implemented to measure children’s liking. This scale was used in most papers assessing likeability and friendship.

**Human Likeness** — The perceived human likeness of the robot was investigated by assessing children’s perceptions of the robot as a social other, mental other, and anthropomorphism. An adapted version of the questionnaires used in [81] was used to capture children’s perceptions of the robot as a mental and social other. Moreover, a modified version of the conceptions of robots questionnaire proposed in [150] was implemented to assess the robot’s anthropomorphism.

**Social Trust** — The trust scale developed by van Straten et al. was employed as a subjective measure of social trust [78]. This scale was designed to capture children’s social trust in robots and was validated with children between 7 and 11 years old.

**Self-disclosure** — In line with empirical evidence suggesting that children’s disclosure of information produces trust [151], in this thesis, a modified version of the Self-Disclosure Task developed in [75] was implemented as an objective measure for social trust. During the task, the robot disclosed two pieces of information (i.e., good and bad information about itself) and prompted for disclosure in return. The number of words, utterances, and type of information disclosed by children were used to measure self-disclosure. The objective was categorising children’s disclosures (positive and negative disclosure, physical, fine motor, cognitive, social skills, unsure, and empathy).

**Competency Trust** — An adapted scale was used to measure competency trust regarding the robot’s perceived helpfulness, reliability, and competence [65, 67, 73].

**Lexical Similarity** — Three different measures were employed to assess lexical similarity or alignment between the robot and the child as an objective measure for competency trust.

- Cosine Similarity: This measure compares the similarity of word frequency vectors using the cosine of the angle between them [152, 153]. The cosine similarity value ranges between 0 and 1, with 1 indicating that the two dialogues are exactly the same and 0 indicating that the two dialogues have no overlap in terms of words.
- Latent Semantic Analysis (LSA): This method uses a matrix factorization technique to find the underlying semantic structure between two speakers in a lower-dimensional space based on their word co-occurrences [154, 155]. This technique captures the semantic similarity in a dialogue.
- N-grams: This analysis involves looking at the frequency of word sequences (i.e., n-grams) that are used by speakers [156]. This technique allows for a more nuanced analysis of lexical alignment, as it considers the specific word sequences used.
Table 5.2. Frequencies for the perceived Role and Gender of the Robot of the user study presented in Paper V.

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<td>Human-Alignment</td>
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<td>Machine-Misalignment</td>
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5.5.3 Results

Shapiro tests for normality were conducted, and in case the data deviated from normal, non-parametric tests were then employed. Post hoc analyses were performed using Bonferroni correction.

Results: Perceived Human Likeness

Children’s responses were coded with scores ranging from 0 to 2 (i.e., 0 = negative or more like a machine, 1 = neutral or both, and 2 = positive or more like a human).

**Anthropomorphism:** The internal consistency of Cronbach’s alpha for this variable was $\alpha = .66$. A Kruskall-Wallis test showed a significant difference in the conditions on perceived anthropomorphism ($H(3) = 9.72, p = .021$). Post hoc tests showed that the Human-Alignment robot was significantly perceived as more human-like ($Mdn = 2, IQR = [1.83 – 2]$) than the Human-Misalignment robot ($Mdn = 1.13, IQR = [0.73 – 1.75], p.adj = .048$), and a trend towards significant compared to the Machine-Misalignment ($Mdn = 1.13, IQR = [0.88 – 1.5], p.adj = .057$). No additional significant results were observed. Results are illustrated in Figure 5.9a.

**Mental and Social Other:** The internal consistency of Cronbach’s alpha for these variables were $\alpha = .78$ and $\alpha = .79$, for mental and social other, respectively. Kruskal-Wallis tests revealed a non-significant difference between the conditions on children’s perception of the robot as a mental other ($H(3) = 2.40, p = .493$) or as a social other ($H(3) = 1.94, p = .585$), as shown in Figures 5.9b and 5.9c.

**Role of the Robot:** Children mostly perceived the robot as a best friend or friend. In terms of gender, the robot was mainly rated as girl-like and gender-neutral. Table 5.2 displays the frequencies for each condition.

Results: Social Trust and Liking

**Subjective Measures:** The internal consistency of Cronbach’s alpha for social trust was $\alpha = .85$, and for liking was $\alpha = .93$. A Kruskall-Wallis showed a non-significant effect of the different levels of human likeness on social trust...
Perceived Anthropomorphism

Perceived Mental Other

Perceived Social Other

Figure 5.9. Effect of Human Likeness in terms of Appearance and Lexical Alignment.
(a) The Human-Alignment was perceived as more anthropomorphic than the Human-Misalignment robot ($p_{adj} = .048$). (b) No significant differences were observed in perceived mental other between conditions. (c) No significant differences were detected in perceived social other between conditions.

($H(3) = 1.05, p = .789$) and liking ($H(3) = 2.64, p = .450$).

Self-disclosure: Children’s responses were transcribed, and spoken words following the robot’s disclosure and prompts were counter, along with the total number of utterances. Not all children disclosed information, and some revealed more than one piece of information. Therefore, the content of the data was analysed after removing words and utterances with no relevant information. For instance, statements like "I can’t" or "Nothing comes to my mind right now" were excluded from the word count and were rated as refusal to disclose/negation instead. Inter-rater reliability with Cohen’s Kappa was performed to assess the accuracy of this measure, resulting in values ranging between 0.77 and 0.97 ($M = 0.85$), denoting high agreement between the coders.

Due to the small sample size and low expended frequencies in the contingency table displaying the frequency distributions of positive and negative disclosure for the four conditions, separate Fisher’s exact tests were conducted for the two independent variables: Appearance and Lexical Alignment. The
A non-significant association was found between negative disclosure and appearance (two-tailed, odds-ratio = 1.8, p = .534). Concerning lexical alignment, the test revealed non-significant associations between this variable and willingness to disclose positive information (two-tailed, odd-ratio = 1.26, p = 1) or negative information (two-tailed, odd-ratio = 2.71, p = .212).

Concerning the effects of human likeness on the number of responses, utterances, and words disclosed by children, a Kruskal-Wallis test revealed a non-significant effect on the total number of responses ($H(3) = 2.70, p = .439$) and the total number of utterances ($H(3) = 3.13, p = .371$). A trend toward significance was observed for the total number of spoken words ($H(3) = 7.21, p = .065$); however, post hoc analyses did not reveal any significant differences between groups.

Concerning disclosure categories, children disclosed more physical and cognitive skills than fine motor or social skills. Aside from this, the qualitative results showed that children who disclosed information in the Human-Alignment ($M = 2.58$) condition revealed less information than in the other conditions, Human-Misalignment ($M = 4.25$), Machine-Alignment ($M = 3.42$), Machine-Misalignment ($M = 3.67$). Children show more empathetic behaviours in the Machine-Alignment and Machine-Misalignment conditions (Figure 5.10).

Figure 5.10. Average of disclosure types children made per Condition. Category “Empathy” is for verbal empathetic behaviours children showed after the robot’s disclosure.
Results: Competency Trust

Subjective Measures: The internal consistency of Cronbach’s alpha for competency trust was $\alpha = .84$. Results showed that children’s perceptions of competency trust were not significantly affected by the level of the robot’s human likeness ($H(3) = 2.39, p = .494$).

Lexical Similarity: Three distinct methods were utilised to examine children’s lexical similarity, also called lexical alignment: cosine similarity, LSA, and n-grams. The lexical similarity was assessed during the story segment (i.e., from when the child expressed their first story idea until they indicated the story’s conclusion). Figure 5.11 displays examples of children engaging with the robot during the storytelling game. The transcription of the interaction adhered to a two-step process. Initially, the stories were automatically transcribed using the Software AssemblyAI API, followed by manual transcript verification using the audio data. A vector containing the robot’s keywords during the storytelling was also generated. This vector comprised words used in the robot’s lexical corpus and was categorised into character, animal, action/attribute, object, and place, representing the terms used for the lexical alignment and misalignment conditions. This approach enabled the examination of lexical alignment concerning the keywords across the entire robot corpus. This analysis provides more insights into alignment concerning word usage beyond the specific keywords used for storytelling. Children’s stories were processed using the NLTK\textsuperscript{3} python toolkit for tokenisation, removal of stop words, and punctuation marks of the data. Scores for cosine similarity, LSA, and 2-grams were obtained for each story interaction. Statistical tests were conducted to compare the conditions under which children and the robot exhibited greater lexical and semantic similarity.

- **Cosine Similarity:** A Kruskal-Wallis test showed a significant effect of levels of human likeness on cosine similarity when using robot keywords ($H(3) = 11.34, p = .010$). Post hoc analysis revealed that children lexically entrained more Machine-Alignment ($Mdn = 0.29, IQR = [0.23 - 0.34], p.adj = .017$) than to the Machine-Misalignment ($Mdn = 0.17, IQR = [0.13 - 0.28]$). When considering the entire robot corpus, a 2-way ANOVA revealed no significant effects of appearance ($F(1,45) = 0.359, p = .552$) or lexical alignment ($F(1,45) = 1.712, p = .197$) on cosine similarity scores (cf. Figure 5.12a).

- **LSA:** There was a significant effect of the human likeness levels on LSA scores when using robot keywords ($H(3) = 12.9, p = .005$). Post hoc analysis revealed that children showed significantly greater lexical alignment with the Machine-Alignment robot ($Mdn = 0.56, IQR = [0.42 - 0.62]$) compared to the Machine-Misalignment robot ($Mdn = 0.29, IQR = [0.23 - 0.34], p.adj = .020$) and Human-Misalignment robot ($Mdn = 0.08, IQR = [0.04 - 0.34], p.adj = .043$). No significant effects

\textsuperscript{3}https://www.nltk.org
were observed on LSA scores when considering the entire robot corpus ($H(3) = 3.79, p = .286$) (cf. Figure 5.12b).

- **N-grams:** A Kruskal-Wallis test did not find any significant effects of the conditions on 2-gram scores ($H(3) = 2.61, p = .541$) as illustrated in Figure 5.12c.

### 5.5.4 Summary

Overall, these results showed that the human likeness levels manipulated in the experiment differed on their level of human-like attributes, and they were coherent regarding the children’s perceived human likeness of the robot. However, this effect did not hold when assessing children’s perceived mental other and social other of the robot.

Subjective measures of trust and likeability did not reveal any significant effect of the robot’s human likeness on children’s perceptions of trust and liking. This is not surprising, as previous research found that subjective measures yield ceiling effects. However, objective measures indicated that distinct levels of human likeness impact children’s trust differently. On the one hand, low levels of human-like attributes, in terms of appearance, benefit social trust and relationship formation. Children were more likely to disclose personal information to the machine-like robot regardless of the level of human likeness regarding responsive behaviour. On the other hand, in terms of responsive behaviour, high levels of human likeness seemed beneficial for competency.
Figure 5.12. Effect of Human Likeness in terms of Appearance and Lexical Alignment on the objective measures for lexical similarity. (a) Children exhibited more lexical similarity in terms of cosine similarity with the Machine-Alignment robot than the Machine-Misalignment robot ($p_{adj} = .017$). (b) Children exhibited higher lexical similarity in terms of LSA score with the Machine-Alignment robot compared with the Machine-Misalignment robot ($p_{adj} = .020$) and Human-Misalignment robot ($p_{adj} = .043$). (c) No significant differences were detected in 2-gram scores between conditions.

trust during task completion. Children are more likely to lexically align with a robot that is also aligned, indicating that children rely more on the robot’s support and help when creating their stories.

5.6 **Paper VI Enhancing Children’s Verbal Creativity through Repeated Interactions**

5.6.1 Contribution to Thesis

This paper contributes to RQ4 by expanding upon the storytelling game and creative measures developed in Paper II. It provides valuable empirical evidence for designing and implementing an online storytelling game that fosters verbal creativity in long-term interactions with artificial agents. Specifically,
this research demonstrates that artificial agents can effectively support children’s learning and enhance their verbal creativity in repeated encounters.

5.6.2 Background and Methodology

Considering the importance of creativity in children’s development, learning, self-expression, and well-being [157], along with the positive impact of social robots on children’s verbal creativity as investigated in Paper II, this study aimed to investigate whether repeated interactions with an artificial agent could facilitate verbal creativity.

The effect of long-term interventions on creativity remains unclear, primarily due to the lack of appropriate longitudinal measures for evaluating creativity [14]. Although research from social psychology suggests that creativity skills can be taught and nurtured, the effects of repeated practice on creative thinking remain poorly understood. For instance, daily practice was found not to impact the number of unique ideas or the average novelty of ideas in divergent thinking tasks. Still, it seemed to facilitate creativity in such tasks [158].

Research investigating the effect of long-term interactions with artificial agents is still emerging. One study found that the NAO robot’s support led children to contribute more to the task and increased their involvement to overcome boredom from repetitiveness over multiple encounters [159]. Another study examined the effects of different types of interaction (individual vs. in-groups) with a storyteller robot on children’s story recall, showing that multiple interactions with the robot promoted children’s social and cognitive skills development, regardless of the interaction type [160].

Furthermore, previous research on creativity with artificial agents has primarily focused on single-encounter interventions, leaving unanswered questions about how repeated interactions influence children’s creativity. This study addressed these gaps by assessing how children’s creative processes, lexical entrainment of the agent’s verbal behaviour, and social behaviour toward the robot change over time.

Experimental Design

A within-subjects user study was designed to investigate the multidimensional nature of children’s trust in robots over repeated interactions. The study had one independent variable Interactive Session with two levels (Session 1 and Session 2). Due to the global COVID-19 pandemic, the scenario was adapted to conduct online user studies. The storytelling scenario was slightly modified as presented in Section 4.4. The virtual version of the Furhat robot was used as the artificial agent.

The study involved a total of 25 children aged 9 to 12 years old ($M = 10.3, SD = 0.8$). Participants were fourth and fifth-grade students from a private school in Bogota, Colombia. The research was conducted using the video
conferencing tool Zoom. Each child engaged in two sessions of the storytelling game with the virtual Furhat—one session per week, with a seven-day gap of zero exposure between sessions. The interaction with the virtual robot did not have a time limit for the children, and the total duration of the study ranged between 20 and 30 minutes per participant. The study was conducted in Spanish, and the robot was teleoperated. Data from 7 participants were excluded for various reasons, including prematurely terminating the activity, participating in only one session, or encountering technical issues. After exclusion, the gathered data from 18 children were used for analysis.

Creativity Measures
Building on the results of Paper II, the creativity measures for Fluency, Flexibility and Elaboration were slightly modified in line with the study’s objectives of assessing the creative process in repeated interactions, as follows:

Fluency — The number of ideas children generated that were relevant to the story plot. Utterances with creative ideas were identified, with each statement containing at least one character and its corresponding action.

Flexibility — The ability to switch from one line of thinking to another. This variable represents the number of categories participants chose for their story plot-related ideas.

Elaboration — The persistence of introducing details. Each idea was evaluated by the number of additional details subsequently provided.

Lexical Alignment Measures
In this study, the robot’s ideas emerged during the storytelling game when children encountered difficulties generating ideas, to encourage children to tell longer stories, or when children asked for the robot’s assistance. To gain a deeper understanding of the robot’s role in supporting children with story creation, a metric was devised to assess children’s acceptance or rejection of the robot’s ideas and the extent to which the robot’s story ideas were incorporated into their stories. As a result, the following measures were created:

Acknowledgement — Whether children acknowledged or ignored the robot’s ideas, an idea is considered acknowledged if the child responded to the robot by saying “that is a good idea”, “yes”, “I like your idea”, or moving the characters or objects. The idea is considered ignored otherwise.

Entrainment — To assess the children’s process of incorporating the robot’s ideas into their story plot, the degree of lexical entrainment of an acknowledged idea was measured on three levels: exact, slight change, and major change.

Social Behaviours Measures
Children’s behaviours related to social interaction were evaluated to determine whether the robot’s behaviours prompted social responses from the children towards the robot. A total of 11 behaviours were coded, encompassing both
robot and children’s verbal behaviour. This measure focused on frequency rather than average. Consequently, the number of verbal social behaviours was divided by the interaction length.

Validation of the Objective Measures
An inter-rater agreement was conducted to validate the objective measures described in the previous sections. In line with the experimental studies of this thesis, behavioural coding using the ELAN software was performed. The measures required an examination of the stories’ content. Hence, the data was coded in the original language (i.e., Spanish). Following standard practice for inter-rater reliability for second language research [161], a single coder who was a native Spanish speaker coded all the data. The coder double-coded 25% of the data selected randomly at different time points (three whole weeks in between). The agreement rates were calculated using the toolbox EasyDIAg, which allows the annotation of time, duration, and category for each behaviour [162]. The inter-rater agreement measures were based on timed-event sequential rating data. A time match is detected if the overlap between two-time sequences surpasses a specific criterion. The default overlap criterion of 60% was used. Cohen’s Kappa values ranged between 0.81 and 0.96 ($M = 0.88$) for categorising occurring behaviours and between 0.46 and 0.83 ($M = 0.73$) for time matching.

5.6.3 Results
Creative Process
Children’s verbal creativity was assessed by analysing the data on the dependent variables: fluency, flexibility, elaboration, and originality. The data for all the dependent variables were non-normally distributed. Consequently, the Wilcoxon signed-rank non-parametric test was employed for statistical analyses.

Fluency: There was a significant effect of Interactive Session on Fluency ($Z = -2.482, p = .011$). Children generated more ideas in the second session ($M = 33.2, SD = 16.8$) than in the first session ($M = 21.3, SD = 14.2$). Results are shown in Figure 5.13a.

Flexibility: A significant effect of the independent variable on Flexibility was observed regarding the category “activity” ($Z = -2.925, p = .003$), indicating that children generated more ideas related to this category in session 2 ($M = 27.3, SD = 12.9$) than in session 1 ($M = 16.1, SD = 11.6$), as illustrated in Figure 5.13b. Non-significant effects were found on the categories “character” ($Z = -0.489, p = .649$) and “scenario” ($Z = -1.067, p = .297$).
Figure 5.13. Effect of Interactive Session (S1: session 1; S2: session 2) on the creative process. (a) The fluency of ideas was higher in S2 than in S1 \((p = .011)\). (b) Flexibility (activity) was higher in S2 than in S2 \((p = .003)\). (c) Average originality did not significantly change between interactive sessions. (d) Elaboration of ideas was higher in S2 than in S1 \((p = .015)\).

**Originality:** The Wilcoxon signed-rank test yielded a non-significant effect of repeated interactions on originality \((Z = -1.241, p = .231)\).

**Elaboration:** There was a significant effect of the independent variable on Elaboration \((Z = -2.353, p = .019)\). This indicates that children’s ideas were more elaborated in session 2 \((M = 45.1, SD = 30.6)\) than in session 1 \((M = 25.5, SD = 22.1)\), as illustrated in Figure 5.13d. As part of an exploratory study, story duration was assessed as a measure of elaboration. This variable was calculated by summing up the time (ss.msec) of each spoken utterance of the variable Fluency. A significant effect was found on **Story Duration** \((Z = -2.016, p = .044)\), suggesting that children’s stories were longer in session 2 \((M = 204.1, SD = 119.1)\) than in session 1 \((M = 137.4, SD = 81.3)\) (cf. Figure 5.14).
Figure 5.14. Effect of Interactive Session (S1: session 1; S2: session 2) on story duration as a measure of Elaboration. Children’s stories were significantly longer in S2 than in S1 (\( p = .044 \)).

Lexical Alignment - Utterances
Qualitative analyses were conducted to explore how children incorporated the robot’s ideas into their stories and to assess the impact of repeated interactions on children’s lexical alignment. The results revealed that more ideas were acknowledged in session 2 (88.9%) compared to session 1 (76.5%). Moreover, children included 76.9% of the acknowledged ideas in session 1 and 72.5% in session 2 (cf. Figure 5.15a).

To further investigate children’s lexical alignment of robot ideas, the aligned story ideas were classified into three levels: exact, slight, and major. Descriptive statistics showed that in session 1, 60% of the ideas entrained had slight changes, and 40% had major changes. In session 2, 48.3% of the ideas were aligned with no changes, 31% with slight changes and 20.7% with major changes (cf. Figure 5.15b).

Social Behaviours
Children’s verbal social behaviours were evaluated as pro-social attitudes towards the robot. The total number of children’s verbal behaviours was divided by the total duration of the storytelling game to obtain the average of verbal social behaviours. A paired sample t-test revealed a significant effect of Interactive Session on Pro-Social Behaviours (\( t(15) = -4.58, p < .001 \)). Children exhibited more social behaviours toward the virtual robot in session 2 (\( M = 0.027, SD = 0.011 \)) than in session 1 (\( M = 0.011, SD = 0.001 \)) (cf. Figure 5.15c).
5.6.4 Summary

Overall, the findings showed that repeated interactions with a virtual robot led to higher creativity in terms of Fluency, Flexibility, and Elaboration, but did not affect Originality. Children told longer stories with a broader variety of categories and more details in the second interactive session. They adopted more robot ideas in the second interactive session, suggesting that children would be more likely to include the robot’s ideas in their stories over time. Moreover, children displayed more verbal social behaviours towards the robot in the second interactive session. These findings indicate that multiple interactions with virtual agents might enhance children’s verbal creativity and willingness to accept the robot’s help while eliciting more positive social cues.
5.7 Paper VII Understanding Children’s Trust Development through Repeated Interactions

5.7.1 Contribution to Thesis
This paper contributes to RQ4 by presenting empirical evidence of how other factors, such as time, affect children’s trust in and relationships with robots. More precisely, by employing subjective and objective measures to capture the multidimensional nature of trust in repeated interactions, this paper emphasises the importance of the robot’s assistance and effective communication between children and robots while collaborating on a storytelling task, focusing on long-term trustworthy interactions.

5.7.2 Background and Methodology
The perception of trust may be significantly influenced by the novelty effect [163], making it uncertain whether children’s perceptions of social robots generalise across repeated encounters. While there is evidence from psychological suggesting that middle-aged children exhibit temporal consistency of trust [164], cHRI studies investigating long-term trust remain scarce [66, 75]. Empirical research presented in Paper IV indicated that children form first impressions of a robot’s trustworthiness within a few seconds. Furthermore, the systematic review in Paper I revealed that interaction length might also impact the development of children’s trust in robots, with shorter interactions yielding higher competency trust and liking. Consequently, there is limited evidence to understand how children’s trust in robots or artificial agents changes across multiple interactions over various time points.

This limited understanding of trust development over time adds to the complexity of comprehending the relationship between children’s trust in robots and their attachment to them when forming relationships. The existing evidence underscores the importance of further investigating how trust and attachment evolve during multiple child-robot interactions. Nevertheless, they also offer insights into the association between children’s trust development and factors such as their developmental stage and the nature of the interaction. As children grow and develop, their understanding of trust, relationships, and privacy may change, affecting their interactions with robots. Similarly, context-related factors, such as the robot’s role, the task involved, and tenure (e.g., several interactions over time), can also impact trust development. This study is the first step in investigating how repeated interactions with a robot impact children’s trust and relationship formation in a storytelling task.

This paper’s experimental design and procedures correspond to Study 5. Therefore, they have already been discussed in Section 4.4.
Trust Measures
Children’s social trust and competency trust in the virtual robot were evaluated using subjective and objective measures. Regarding social trust, the trust scale developed by van Straten et al. was employed as the subjective measure [78], while the self-disclosure tasks introduced in [75] were utilised as the objective measure. For competency trust, the trust scale implemented in [73] was adopted. Likeability was assessed using self-report questionnaires, consistent with the other papers of this thesis.

5.7.3 Results
Social Trust and Liking:
Subjective Measures: A Wilcoxon signed-rank test revealed a non-significant effect of the Interactive Session on the subjective variable of social trust ($W = 64.0, p = .53$). Moreover, non-parametric tests revealed a non-significant effect of repeated interactions on liking ($W = 54.0, p = .67$).

Self-disclosure: A Wilcoxon signed-rank test revealed that Interactive Session did not significantly affect the number of total words ($W = 47.0, p = .09$), responses ($W = 25.0, p = .26$), or the number of words following robot’s disclosure ($W = 48.5, p = .51$). However, Interactive Session had a statistically significant effect on the total number of words after the robot’s prompt ($W = 31.5, p = .018$). Children disclosed significantly more information after the robot’s prompt in session 2 ($M = 25.55, SD = 13.75$) compared to session 1 ($M = 17.55, SD = 16.12$). Results are shown in Figure 5.16a and Figure 5.16b.

Competency Trust
Results showed a significant effect of Interactive Session on Competency Trust ($W = 29.0, p = .04$), children rated the robot as more competent and reliable in session 2 ($M = 4.51, SD = 0.51$) compared to session 1 ($M = 4.33, SD = 0.45$), as illustrated in Figure 5.16c.

5.7.4 Summary
Although there was no significant effect of repeated interactions on subjective social trust and liking measures, objective measures showed that children disclosed significantly more information in response to the robot’s prompt during the second encounter. This observation suggests that children may have felt more connected to the robot in the second interaction. They were more inclined to share personal information, indicating that multiple encounters can promote closeness and rapport by eliciting more positive social cues.
Figure 5.16. Effect of Interactive Session (S1: session 1; S2: session 2) on children’s self-disclosure and competency trust. (a) After the robot’s prompt, the total number of words was significantly higher in S2 than in S1 (p=0.018). (b) The total number of words disclosed after the robot’s disclosure did not significantly change between interactive sessions. (c) Children’s competency trust was significantly higher in S2 than in S1 (p=0.042).

The children’s competency trust in the virtual social increased in the second encounter. This result may be linked to the findings on lexical alignment observed in Paper VI. Lexical alignment refers to the phenomenon in which conversation partners adapt their language and communication style to match one another, thereby improving understanding and rapport. As such, children adopting more robot ideas in the second interactive session might signal the children’s endorsement of the robot’s help, which in turn contributes to their perception of the virtual robot as more competent and reliable.
6. Discussion

6.1 Trust in cHRI (RQ1)

The systematic literature review showed that children’s trust in robots had been investigated in child-robot interactions along two main dimensions: social and competency trust. Social trust pertains to the interpersonal aspects of trust, such as how comfortable children feel sharing personal information with the robot or engaging in collaborative tasks [63, 78]. On the other hand, competency trust relates to children’s beliefs about the robot’s abilities, expertise, and reliability in performing tasks [72, 73]. In addition to these two dimensions, other constructs related to pro-social attitudes are used interchangeably with trust. These constructs may include perceived friendliness, empathy, and likeability. In this work, a number of contributions are made to the field of cHRI concerning how different factors might affect trust dimensions in different ways.

Regarding social trust, the meta-analysis revealed a lack of significant effects despite the large number of studies assessing this construct. One possible explanation for this result is the variation across studies. This variation may stem from several factors, such as differences in the operationalisation of trust and methods to capture it. For instance, some studies focused on the interpersonal aspect of trust [75, 83], while others focused more on broader constructs such as likeability and friendliness [67, 76]. Moreover, methodological differences in measuring social trust can contribute to this variation [165, 166].

When evaluating competency trust, an overall negative effect of human-like attributes on this trust dimension was observed. This finding suggests that, in all cases, more human-like behaviour and embodiment may adversely impact competency trust. One possible explanation is that more human-like robots generate higher expectations for competency trust [64, 91, 167, 168]. The increased expectations of performance due to the human-like appearance and behaviour might result in disappointment when the robot does not exhibit the anticipated level of expertise, reliability, or capability, and, therefore, decreasing competency trust.

Several factors were investigated to provide a more comprehensive understanding of the impact of different factors on trust, as discussed below:

Age

When considering both social and competency trust dimensions, age was negatively associated with competency trust, proving that children’s development
stage influences how they interact with social robots [167]. This finding aligns with previous research indicating that younger children (ages 6-10) tend to conceptualise the robot more as a social other [81], persuasive and credible agent [90] than older children. Moreover, this implies that younger children might be more susceptible to manipulations of robot embodiment and behaviour. A possible explanation draws from cognitive and social developmental theories [33, 169]. Younger children often have a more limited understanding of artificial agents’ capabilities and may anthropomorphise robots more readily, attributing human-like qualities, intentions, and emotions to them [167]. As children grow older, they develop a more sophisticated understanding of the differences between humans and robots, which may decrease competency trust as they become more critical of the robots’ abilities.

**Interaction Type**
The interaction type is a context-related factor, associated with the nature of the interaction that may significantly influence how children perceive and trust robots. Specifically, human-like attributes have been positively associated with competency trust in studies where playing a game with the robot was the main task. However, the effect was reversed when considering social trust alongside competency trust. This could be because social trust encompasses relational aspects [64], which may be influenced by factors other than competency trust.

Another possible explanation for the observed adverse effect on children’s competency trust in the robot could be attributed to the lack of adaptation in the games. Often, games are designed with a fixed structure and limited variability, which can result in children mastering the gameplay more quickly. Consequently, their reliance on the robot decreases, as they no longer perceive it as a valuable source of guidance or support during the game. Designing different activities or games that adapt to children’s learning needs and preferences could mitigate these effects and improve trust development as the robot provides relevant and engaging support throughout the game experience [170, 171].

**Robot Type**
Humanoids were found to negatively impact competency trust when combined with social trust. However, this result should be interpreted cautiously, as most studies included in the meta-analysis were conducted using NAO (SoftBank Robotics). This is a limitation to concluding how physical robot embodiment influences trust, as the overrepresentation of NAO as the robot model may not fully capture the diverse effects that different robot embodiments can have on children’s trust [172]. Recent research has focused on designing low-cost robots suitable for cHRI that are customisable to users’ needs and preferences [173]. Utilising different types of robots could provide more insights into the effects of embodiment and physical robot’s appearance on children’s trust.
Robot-related Factors
Robots that made errors showed a significant positive effect on competency trust. This suggests that children trust robots that make errors more, which is surprising and contradicts studies on adults where errors violate competency trust [70]. One explanation could be that children perceive and react to errors differently than do adults [44]. Concerning robot behaviour, there was a negative effect of human-like behaviour on competency trust in the combined social and competency trust model. Once again, this finding challenges the assumption that human-like behaviour is always beneficial in child-robot interactions [174], and highlights the importance of carefully designing robot behaviour to foster trust in educational settings.

Teleoperation vs Autonomy
The results indicate that robot operation significantly influenced the combined social and competency trust model, suggesting that human-like attributes negatively affected competency trust in studies where robots were teleoperated. However, this result should be interpreted with caution because the Wizard of Oz (WoZ) was the most prevalent in the studies analysed and is the most common method of operation [2]. Teleoperated robots might embody certain features that autonomous or semi-autonomous robots do not, which could create an inconsistency between human-like attributes and competency trust. Despite the current technological limitations of social robots, WoZ designs enable the exploration of features that are not yet possible with autonomous robots [17, 44, 170, 175]. As technology progresses, comparing WoZ with autonomous robot designs will provide a more nuanced understanding of how human control affects different aspects of the interaction, such as trust.

Measures of Trust
Different kinds of measures showed different results on children’s trust. For instance, objective measures for social trust, such as self-disclosure, seem to capture more natural interactions and reduce biases compared to subjective measures [176]. However, self-disclosure should be carefully designed to capture the intended trust outcome [28, 75], as they might be challenging to quantify and highly depend on individual variations [151].

In addition, when combining social and competency trust, more human-like robots are seen as less skilled when employing objective measures. Similar effects were observed on the combined social trust and liking model, suggesting that using objective measures decreases likeability for robots with more human-like features.

These results emphasise the importance of developing suitable methods and measures for evaluating trust in cHRI studies as subjective and objective measures appear to yield distinct responses [165, 174]. For instance, subjective measures, like questionnaires, may be prone to response biases or ceiling effects in children [146]. In contrast, objective measures, such as behavioural...
observations, may be affected by the presence of an experimenter or other contextual factors.

6.2 Context, Learning, and Trust (RQ2)

The previous section discussed that the nature of the interaction could affect how children interact with and trust robots. In this work, collaborative storytelling was chosen as the main task, and regulatory focus-driven emotional strategies were implemented in the game to foster creativity and trust in children. Overall, findings suggest that engaging in a collaborative game with a social robot encourages children’s creativity. In addition, children in the promotion condition were more creative in terms of fluency (i.e., the number of ideas) in the promotion condition. Conversely, children were more original in the prevention condition. This suggests that the robot’s social behaviour and interaction style influenced the children’s task performance and highlights the importance of understanding how a robot’s behaviour can impact children’s engagement and learning. These results align with previous research suggesting that the robot’s social behaviour influences children’s creativity [14].

Regarding the effects of regulatory focus-driven behaviours on children’s perceptions of the robot in the storytelling game, results demonstrated that the prevention focus elicited higher likeability in children than the promotion focus. These findings suggest that the robot’s disclosure of being in a vulnerable situation may foster a greater sense of companionship in children. This contributes to previous research indicating that vulnerability increases trust and closeness in robots [177]. These results offer valuable insights into how children evaluate companionship with robots when collaborating on a specific task, which may be linked to trust development and relationship formation with robots [64].

Conversely, the regulatory focus design did not influence children’s trust in robots for any of the implemented objective and subjective measures. Despite the absence of significant effects, an interesting pattern emerged. The subjective and objective measures, intended to assess the same aspect of trust, showed a significant negative correlation. This suggests that these two types of measures may have captured different aspects of children’s trust or may be influenced by factors that are not necessarily aligned. This result is supported by recent research highlighting the challenges when measuring trust in robots, as different methods point to different directions [165, 174]. It also supports the finding discussed in the previous section about how objective and subjective measures affect trust dimensions in distinct ways.

The observed discrepancy between subjective and objective trust measures underlines the importance of carefully selecting and validating assessment methods in cHRI studies, as indicated in [78]. First, measures might only generalise across some scenarios or contexts, as trust is highly complex to
capture. Moreover, children might use different sources of information when deciding whether to trust a robot [63, 64, 72]. Second, the interpretations of scores should be approached with caution, as children might have different understandings of what “trust” mean to them. These definitions might not be consistent across participants and may differ from adults’ perceptions [167, 178].

Another aspect that could explain the lack of significant effects of trust measures is the nature of the task. In this case, the child and the robot were asked to collaborate on achieving a goal (i.e., getting out of the spaceship). Successful cooperation in attaining the goal could have strengthened children’s perception of support and companionship from the robot, which the robot’s expressive behaviour may have enhanced during this activity, and present in both conditions. Previous research has indicated that expressive behaviour can positively impact children’s relationships with robots [16, 89, 93, 179].

In addition, cHRI studies have indicated the link between collaborative task performance and perceived robot reliability [179, 89]. In the context of the storytelling task, children completed the task by narrating their stories to the robot. As a result, the impact of emotion-driven regulatory focus behaviours might not have been adequately captured by the subjective measures employed in the study. This, again, supports the previous assertions regarding the importance of designing accurate trust measures that are sensitive to the specific tasks and contexts in which they are applied [165].

6.3 Robot Appearance and Behaviour (RQ3)

Elaborating further on the influence of a robot’s appearance and behaviour on children’s trust, the discussion presented in this section focuses on the role of human-like attributes in robots, as they have been largely used in cHRI and have a substantial impact on children’s trust in the robot. This impact can be attributed to children’s tendency to anthropomorphise robots more than adults, attributing human-like qualities and intentions to them [58, 86].

Concerning human-like non-verbal behaviours, particularly facial expressions of emotions, first impressions played a pivotal role in shaping children’s perception of a robot’s competence and likeability. Within just a few seconds, these perceptions predicted children’s judgments about a robot’s trustworthiness based on non-verbal cues, highlighting the importance of first impressions when interacting with robots. These initial judgments can have a lasting influence on their interactions with social robots over time [28, 180]. This finding adds to the current body of knowledge, indicating that children are susceptible to robot non-verbal behaviours in first encounters.

Human likeness was also examined in terms of verbal behaviour, specifically responsiveness. While subjective trust measures did not reveal any impact of human-like verbal behaviour, objective measures indicated that chil-
Children were more likely to mirror the robot’s behaviour when it was responsive and matched the context of the task. This result offers two contributions. First, human likeness in terms of responsiveness could be beneficial for competency trust when a child and robot collaborate on a task. Second, this observation has methodological implications, as it introduces an objective measure tailored to the task: lexical alignment in storytelling. This measure can help ensure that trust assessments accurately capture the nuances of children’s trust in robots when they depend on the robot’s information to support their learning.

In addition, visual and auditory cues were employed to design robots with low and high levels of human-like appearance. Consistent with previous findings, subjective measures did not reveal any effect of appearance on social or competency trust. However, children were more inclined to disclose personal information to a machine-like robot. One possible explanation for this outcome is that children might feel more at ease with robots embodying low human-like attributes when sharing personal information in collaborative tasks, as these robots may appear less judgmental or intimidating.

These findings provide insights into how human likeness should be approached and implemented in CHRI studies, as different human-like attributes impact trust dimensions differently. On the one hand, human-like behaviour may benefit competency trust when children engage in a collaborative game with the robot, which is a context-related factor. In this work, the robot’s responsive behaviour was designed to support children’s story creation. It could lead to children’s expectations regarding the robot’s capabilities as a storyteller being met when the robot provided ideas that aligned with their stories. This enriches the current literature, which suggests that humanoid robots elicit more mirroring behaviours in children [117]. On the other hand, human-like attributes in terms of appearance seem more important when assessing children’s social trust. The results described in this thesis provide empirical evidence supporting findings from previous studies suggesting that moderate and low human-like attributes foster more prosocial attitudes in children [118, 119].

The human likeness of a robot is directly connected to its embodiment. Although this thesis did not specifically examine the effects of different robot morphologies (e.g., anthropomorphic vs zoomorphic) or embodiments, it can offer insights into how robot embodiment with varying human-like attributes might be designed to foster children’s trust in robots. Recent research has discovered that a robot’s morphology and embodiment do not influence children’s selective trust strategies [86, 181]. However, this finding does not imply that embodiment is unimportant in fostering trust. Instead, as this thesis suggests, how human-like attributes are incorporated into a robot’s design might be more crucial in determining children’s trust, the way they rely on the robot’s help, and their social behaviours toward it. Therefore, the contributions of this work encourage researchers to consider how the combination of appearance,
behaviour, and responsiveness in a robot’s embodiment can contribute to developing trust, particularly in child-robot interactions.

6.4 The Role of Time (RQ4)

The long-term goal of artificial agents, particularly social robots, is to support sustained interactions. The results presented in this thesis serve as a starting point for understanding how trust evolves dynamically over time and which aspects are significant when children collaborate with a robot to support their learning.

Regarding creativity, the second encounter with the social robot increased children’s creativity across all measures except originality. One possible explanation for this is that children became more familiar with the activity and, as a result, generated and elaborated on more ideas. However, since the application remained the same, their stories may have been limited to the topics, characters, and objects present. Moreover, during the second encounter, children showed a greater tendency to lexically entrain the robot’s ideas. This suggests that children relied more on the robot’s assistance in the second encounter than in the first. There are two possible explanations for this. First, this finding may imply that as children become more familiar with the robot and the activity, their trust in the robot’s input may increase—as supported by the subjective measures of competency trust—leading them to incorporate more of the robot’s suggestions into their stories. Similar findings on story recall support this assertion [16, 146]. Second, it could also suggest that the activity became repetitive in the second encounter; therefore, children used the robot’s ideas more to complete the task. In either case, children are more likely to rely on the robot as time progresses. This brings opportunities for future research to design robots that can better support learning, in this case, originality to foster children’s creativity in storytelling, as recent research indicates [30].

Concerning social trust, results showed that children were more likely to disclose more information and exhibited more social behaviours towards the robot in the second encounter than in the first encounter. These results suggest that children may have felt closer to the robot, indicating increased social trust. However, subjective measures did not reveal the same effect. One possible explanation is the incongruency between the instruments used to capture the same outcome. The subjective measures used to capture social trust might not be appropriate for repeated interactions. This assertion consistently supports the need for valid measures tailored to the task and interaction. Another explanation is that although self-disclosure is considered a predictor of children’s trust in other people [151, 182], in this context, it could indicate the development of a relationship with robots [75, 87], making children feel comfortable sharing information with robots, but not necessarily trusting social robots more. These findings underscore the complexity of understanding the
relationship between children’s trust in robots, their attachment to them, and their willingness to share personal information. Trust and attachment appear interconnected, but the extent to which they are linked may vary depending on the specific context and circumstances.

These findings highlight the importance of considering trust development and the dynamics of child-robot interactions over time. As trust grows, the collaboration between the child and the robot may become more effective, with children being more open to the robot’s help and support. Moreover, children’s perceptions of the robot’s trustworthiness change as they gather more evidence about its performance and capabilities, an effect that has been studied recently with adults [183]. Understanding and supporting this process in children is crucial for designing social robots to effectively assist them in various tasks and activities during long-term interactions.

6.5 Design Opportunities

The implications and interpretations of the findings of this thesis work offer several design opportunities for future research, as outlined below:

**Trust Measures.** The discrepancy between subjective and objective trust measures highlights the need for methodological advancement in cHRI. Developing more reliable and valid subjective and objective trust measurement tools tailored to the interaction context will enable researchers to capture the complexity of trust in cHRI more accurately, leading to a more comprehensive understanding of trust dynamics and their impact on learning outcomes. Future research should focus on understanding the factors influencing the relationship between these two types of trust measures.

**Human Likeness.** The effect of human-like attributes seems to be associated with the context of the interaction and collaborative tasks. Therefore, it is crucial for future research to carefully consider the degree of human likeness when creating social robots for educational purposes. Striking the right balance between human-like attributes and realistic performance capabilities can help prevent the negative impact of over expectations on trust. This may help create social robots that foster children’s trust, leading to more successful and engaging educational interactions in cHRI, as well as their potential impact on long-term interactions.

**Developmental Stage.** Considering children’s age and developmental stage when designing and evaluating robots is essential. It helps to better adapt robot interactions to different age group’s specific needs and expectations.
Longitudinal Evaluation. Designing longitudinal studies that explore children’s trust development in robots over extended periods could help researchers identify how children adapt their trust while interacting with the robot. Moreover, it could provide more information about how robot behaviour and personalisation should be implemented to support trust development and learning.

6.6 Ethical Considerations

The work presented in this thesis explored how robots can serve as companions to support children’s learning while examining the effects on children’s trust and relationship with robots. Furthermore, this work aimed to provide design opportunities—based on the empirical evidence gathered—to help future research develop trustworthy robots. However, implementing robotic and AI systems raises some concerns about children’s rights and well-being. For instance, the United Nations Children’s Fund (UNICEF) has developed Policy guidance on AI for children to build systems that protect, provide for, and empower children [184]. This section discusses potential ethical concerns that may arise in the context of evaluating trust in cHRI, how these concerns relate to existing literature, and possible solutions.

Diversity. The results presented in this thesis are based on three specific user groups across three different countries. While this provides a wider range of children’s perspectives on the implementation of robotic system when studying trust, it does not cover the whole children population. To ensure diversity and inclusion in the development of robotic systems, it is crucial to involve a broader range of children with diverse cultural backgrounds. By incorporating the perspectives of children from various backgrounds, researchers and designers can better understand the unique needs, preferences, and challenges faced by different groups, ultimately creating more inclusive and effective child-robot interactions [185, 186].

Children’s Data and Privacy. The findings of this work showed that children are likely to socially trust the robot by sharing personal information with it. While this could signal engagement and rapport that could benefit the interaction, this information must be handled carefully to prevent misuse and ensure compliance with relevant data protection regulations. Moreover, children’s data—including their preferences, behaviours, and interactions with robots—is used to design robots that adapt to their specific needs. Therefore, employing anonymisation and secure storage methods to protect children’s data is crucial [187], as well as being transparent with children about how their data will be processed and stored [188].
Trust Usage. Developing social robots that foster children’s trust may lead to concerns about emotional attachment and misuse of technology when trust is established. For instance, results could be exploited for unethical purposes. It is vital to ensure transparency about the capabilities and intentions of the robot and engage in continuous dialogue with stakeholders, including children, parents, educators, and researchers from different disciplines to understand and assess possible risks that might have arisen [189, 190, 191, 192, 193].

Deception. Questions have been raised about the potentially deceptive nature of studies using teleoperated robots. Children might feel betrayed when they discover the deception, which could eventually negatively impact their trust and well-being. It is crucial to prioritise the system’s transparency and inform children, parents, and teachers that a human controls the robot. This approach could help to mitigate any feelings of betrayal, maintain their trust in the research, and consider the ethical implications of deception [194, 195].
7. Conclusion

The goal of this thesis was to investigate trust in child-robot educational interaction, and its role on children’s learning. This goal was accomplished by first identifying the gaps in the literature and assessing how trust has been defined and measure in cHRI. Moreover, four user studies were carried out to gather evidence about the effects of various factors, such as regulatory focus-driven behaviours, robot human likeness, and long-term interactions, on children’s trust and attachment to social robots. The main findings of this thesis are outlined below:

- Highlight the importance of considering a multidimensional approach to understanding children’s trust in social robots. More precisely, social trust and competency trust, and its relation with likability and friendliness. Results demonstrated that different dimensions of trust developed differently and could be highly subject to the task and context.

- The results showed that subjective measures failed to capture any effect of the factors investigated in the empirical studies on social and competency trust. In contrast, objective measures, such as self-disclosure, social behaviours towards the robot, and lexical alignment, provided different insights about children’s trust in the social robot. This distinction between subjective and objective measures underscores the importance of the design of reliable measures tailored to the task, children’s stage development, and trust dimension.

- The findings challenge the assumption that human-like attributes in social robots are always beneficial. More specifically, lessening human likeness in the appearance of an already highly human-like robot promotes social trust, whereas high human-like behaviour benefits competency trust. Instead, they emphasise the need for a nuanced approach in designing robot behaviours and appearances that adapt to specific interaction scenarios and trust dimensions.

- In terms of verbal creativity, the results underscore the importance of designing robots that provide emotionally engaging and contextually relevant input, while also being sensitive to children’s preferences and comfort levels. By doing so, it is possible to foster trust and promote collaborative learning experiences between children and robots.

- Emphasise the importance of longitudinal studies to better understand trust development in child-robot interactions by providing empirical evidence that children’s trust, task performance, and behaviour change as time progresses. Exploring how trust evolves over time could provide
insights into supporting and maintaining trust, ensuring successful and sustainable educational interactions.

Moreover, this thesis made contributions concerning the software implementation of the scenario. First, developing the storytelling game for children served as a platform for studying trust and verbal creativity customisable to physical and online studies. Second, the customisable robot behaviours and appearances allow for studying different robot-related factors in various studies. Third, integrating objective measures for creativity and trust tailored to the activity context allows a more accurate understanding of trust and its effect on learning. Repositories containing the methods, assessments, and data were made available and included in this thesis’s publications. The repository of Paper V will be available in the future.

These contributions significantly expand the current understanding of trust dynamics in cHRI and inform the design of more effective and engaging educational robotic systems.

7.1 Limitations and Future Work

The first limitation of this thesis work relates to the selection of papers included in the meta-analysis. Trust, being a multifaceted construct, has been defined and studied in various ways across different studies. This variation was evident in the papers included in the analysis. Therefore, it might have been possible that the keywords used for the literature search did not encompass the entire range of relevant studies, potentially leaving out important research related to trust. Therefore, future research could expand the scope of the search to include a more diverse literature search to ensure a broader perspective on trust in cRHI, considering its complexity.

The second limitation pertains to the choice of robot morphology used in the studies. Both physical robots (EMYS and Furhat) employed in the research exhibited some degree of anthropomorphism. This anthropomorphic design may have triggered certain expectations or biases in the children, influencing their trust and interaction dynamics. Consequently, the results obtained from these studies might not generalise to other robot morphologies, such as zoomorphic and mechanomorphic designs. Future research could further explore the effects of different robot morphologies and embodiments on children’s trust and investigate how specific human-like attributes contribute to various aspects of trust development.

The third limitation involves using the virtual Furhat robot in the repeated interaction study. Although this decision was made in response to the global pandemic, virtual robots may elicit different responses in children than physical robots. Therefore, the insights gained from this study may be only partially transferable to scenarios involving physical robots. Future research should focus on comparing the dynamics of trust and interaction between children
and both virtual and physical robots, as children may develop distinct perceptions and expectations for these different embodiments. Moreover, future work should also focus on investigating the effects of these embodiments on long-term interactions over more encounters and periods of time.

Another limitation pertains to individual differences. While this research focused on designing a collaborative game and assessments that fit children’s needs, it did not delve into the nuances of individual differences among the children. Future work should consider age, gender, prior experience with robots, cognitive abilities, personality traits, learning preferences, and cultural backgrounds to better understand how these differences impact children’s trust in robots and their collaboration dynamics.
Den snabba tekniska utvecklingen som ägt rum under det senaste decenniet har haft betydande implikationer för flera olika områden, och utbildningstillämpningar har varit ett av de allra mest attraktiva. Sociala robotar spelar en viktigt folk i sådana tillämpningar eftersom deras fysiska närvaro verkar fördelaktiga för att öka kognitiva och affektiva utfall. Dessutom kan deras förmåga att förkroppsliga en mängd olika fysiska utseenden och sociala beteenden (både verbala och icke-verbala) påverka hur barn uppfattar och interagerar med dessa representanter. Eftersom interaktionen bygger på sociala och kognitiva processer är det mycket viktigt att förstå hur sociala robotar påverkar barns förtroende och därmed relationsbildning och tycke i scenarier där lärande och samarbete krävs för lyckade utbildningsinteraktioner.

Förtroende för sociala robotar är ett grundläggande inslag i interaktioner mellan barn och robotar eftersom det kan vara avgörande för att upprätthålla lyckade och långsiktiga interaktioner. Därför är det avgörande att studera hur barn konceptualiserar förtroende och rollen som de tillskriver det när de utför samarbetsbaserade utbildningsuppgifter tillsammans med robotar för att kunna implementera sådan teknik i klassrummet. Detta är viktigt eftersom insikter om hur barn uppfattar robotar som förtroendeinsivande kamrater när de utför en samarbetsbaserad inläningsuppgift kan utvinnas ur att studera sociala robotars sociala och kognitiva förmågor. Syftet med denna avhandling är att förstå hur robotrelaterade funktioner och beteenden påverkar barns förtroende för och beteende gentemot robotar i en samarbetsbaserad kreativ uppgift.


Vad gäller den roll som barns förtroende för robotar spelar i deras lärande skapades ett samarbetsscenario med två huvudsakliga mål. Det första målet

Andra faktorer påverkar också hur barn interagerar med robotar. Dessa faktorer är relaterade till roboten i sig. I denna avhandling undersöktes ansiktsuttrycken för känslor och mänsklig likhet gällande robotens fysiska utseende och beteenden för att bättre förstå hur barn antropomorfiserar och interagerar med olika robotar.

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