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# Playing with robots in a nursery: a sociomaterial focus on interaction and learning

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**Abstract**
In the field of educational robotics, it is important to understand the processes trough which child-robot interactions are established during play activities. In terms of socio-material characteristics, robots can vary widely, from more mechanical robots to more anthropomorphic ones. Research has shown that the degree of anthropomorphization of the robot has an impact on how children perceive and interact with the robot. The role of the socio-material characteristics is still poorly explore in the 18–36-month age group. The aim of the study was to investigate how the presence of two robots, which differed in their socio-material characteristic of anthropomorphization, shapes both the individual and group play activities of 25 children aged 18–36 months. The children were observed during free group play sessions in which they had access to two types of robots: Idol, with more human-like features, and Pixy, a more mechanical robot with minimal anthropomorphism. Observations made through video recordings were transcribed. Qualitative analysis was conducted, and six units of analysis of children's interaction with robots were identified. The main finding from our study is that children as early as 18 months are sensitive to the socio-material characteristics of the robotic artefact, influencing the way they interact with the robot and with each other. Notably, children displayed more imitation behaviors and social interactions with Idol, the more anthropomorphic robot, while Pixy, the mechanical robot, was primarily explored for its mechanical features. From an educational point of view, we highlight the importance of the construction of the learning environment and the choice of materials to propose to the children in play; the robot could be used to reinforce symbolic play, imitation, and to support group interaction.

**Keywords** Child-robot interaction · Educational robotics · Sociomateriality · Anthropomorphism · Learning environments · Early childhood play activities · Nursery

## Introduction

In recent years, the study and application of robotics has considerably increased, both on the technical level (what can such an artefact do and how can it constitute a form of replacement and/or support for human activity; Marchetti et al., 2018; Law et al., 2022) and on the

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economic, legal, and ethical level (what it is legitimate for a robot to do, what prospects does it open up and what concerns does it raise (Coeckelbergh, 2022). These issues also have major repercussions in the educational field (Alnajjar et al., 2021; Belpaeme et al., 2018) as well, since robotics and AI allow us to imagine new forms of educational activity that are often envisaged as revolutionary compared to traditional teaching models.

In educational settings, a variety of robots have been used to facilitate learning activities, particularly with young children. For example, the NAO robot has been widely employed in studies focused on enhancing language skills, social interaction, and cooperative play in children aged 3–7 years (for a review, see Belpaeme et al., 2018). This humanoid robot's expressive gestures and verbal communication capabilities make it an effective tool in creating engaging learning environments. Similarly, robots like KASPAR and QT have been employed in studies with school-aged children with autism spectrum disorder to promote social skills and interaction in educational contexts (El-Muhammady et al., 2022; Wainer et al., 2014). Additionally, simpler robots like Bee-Bot have been used with children aged 5–6 years to teach basic programming concepts and problem-solving skills through play-based activities to foster the executive function skills (Di Lieto et al., 2017). This robot does not have a humanoid design but still fosters cognitive development by encouraging children to plan sequences and think logically. Studies by Kory Westlund et al. (2017) have also explored how non-humanoid robots such as Tega, a storytelling robot, enhance early literacy skills in children aged 4–7 by engaging them in interactive narratives and language-based games. These examples underscore the versatility of robots in facilitating diverse learning activities, ranging from social skills to cognitive development, across various early childhood age groups.

One fact is certain, however: the mere presence of a robotic artefact in the classroom immediately arouses the curiosity of children who are fascinated by this new form of simulation of human behavior. Even casual observations can easily testify to the attractiveness of the robot to children and its extraordinary power to change the dynamics within educational activity spaces. Of course, the robots' extraordinary force of attraction does not in itself verify the pedagogical potential of this type of object. In fact, the implementation of robots in educational environments undoubtedly requires more knowledge of how activity systems are influenced by them. This objective is obviously very complex, but it is possible to proceed by identifying some of the constituent elements of the artefact in order to assess their relevance in the modulation of educational relations. The choice can be made from the existing literature by first selecting those characteristics of the object that potentially have the greatest impact on relationship building. Before going into the details of the scientific literature of reference for this research work, it should be pointed out that in a broader sense, it takes into account two important landmarks of cognitive development theories. First and foremost, this inquiry embraces the concept of "cultural artifacts," inspired by Vygotsky's seminal works (Vygotsky, 1967, 1978), which posit that non-human elements within psychological activities play an active and constructive role in cognitive development. Within this context, it can be observed the transformative nature of objects through the crucible of social and cultural processes, wherein these objects metamorphose into tools that buttress diverse forms of activity—either as external adjuncts or internalized constituents (as elucidated in the notion of "psychological tools" by Friedrich 2014).

Secondly, in elucidating children's interactions with robots, we shall draw from select postulations embedded within Piaget's theory of cognitive development. Specifically, our focus will center on aspects underscored by Piaget in delineating how children construct their cognitive understanding of the world during play activities (Piaget, 1937), as well as in subsequent scholarly contributions.

The aspects of Piaget's theory that will be taken into account in this paper refer mainly to (a) the different ways of interacting with objects that characterize the different stages of cognitive development; (b) the emergence, especially in the early stages of psychological development, of animistic representations of objects into which the child integrates. Moreover, as the following literature also emphasizes, the construction of the world from the child's point of view is entirely characterized by the interweaving of real and imaginative elements, which manifests itself primarily in play (Pelaprat & Cole, 2011).

Although Piaget and Vygotsky offer explanations of psychological development moving from quite different epistemological positions, they express less distant views on the fundamental role of symbolic thinking in the child and the imaginative and creative capacities offered by this new mode of iteration with the physical and social worlds (Lourenço, 2012).

It is precisely this aspect that makes the study of child-robot interactions interesting at an age group when we are witnessing the progressive consolidation of symbolic skills that are put at the service of the more general ability to understand and interpret the world around us (Cattaruzza et al., 2024; Iannaccone et al., 2019; Marchetti et al., 2018; Manzi, 2018). When children play, they walk a line between reality and fiction; they often attribute emotions or personality to toys, and this is something already known; however, the interaction with socially interactive robots changes this binary distinction and lies in a borderline area called "a little bit alive" (Turkle et al., 2006), a borderline in which a robotic doll could be considered a little bit more alive than other dolls. In many cases, imagination enables the child (and the adult!) to complete scenarios and predictions for which adequate information is lacking. This provides relevant clues as to how the child views reality and how he or she uses already available information in interacting with the world. In this context, children's interactions with social robots share many similarities with their behaviors toward animals, which can also spark imaginative and symbolic play (Jalongo, 2015). Just as children often attribute emotions, intentions, and personalities to animals (Di Dio et al., 2018), they tend to project human-like qualities onto robots, treating them as social companions rather than mere objects (Manzi et al., 2020a, 2021). This parallel is significant in the development of symbolic thinking, where both robots and animals act as entities that bridge the gap between the real and imaginary worlds. By engaging with these non-human agents, children are encouraged to explore empathy, role-playing, and narrative construction, which are fundamental aspects of cognitive and social development.

## Child-robot interaction in early education

Educational robotics for children aged 18–36 months is an emerging field, rich with potential yet marked by a notable scarcity of systematic studies. Our research seeks to fill this gap, exploring how toddlers interact with robots that vary in physical anthropomorphism within a nursery setting.

The seminal work of Tanaka et al., (2007) in introducing social robots into nursery environments paved the way for understanding how young children can engage meaningfully with robots. This study highlighted toddlers' ability to engage in complex behaviors such as imitation and role-playing in response to robotic stimuli, emphasizing the adaptability of young minds to technological interactions. Building on this, studies by Manzi et al., (2020b) and Fitter et al., (2019) focus on how toddlers interact with the physical attributes of the robots, such as eye contact and gesture responses. These studies underscore the significant impact of robot design on children's engagement levels. Additionally, Movellan et al. (2009) and Scassellati et al. (2018) show that social robots can foster cooperative learning and enhance social skills among young children, including those with developmental fragilities. In the context of language development, Kory Westlund et al. (2017) found that storytelling robots can significantly increase language activity and storytelling skills in young children, pointing to the instrumental role of robots in early language and literacy development. Belpaeme et al., (2018) provide a pivotal perspective on the integration of robots into educational environments. This review explores the different roles that social robots can play, such as teacher, tutor, peer, or novice, and the profound impact these roles can have on the learning environment, highlighting the versatility of robotics in education and its potential to reshape traditional teaching models. Van Straten et al., (2020) provide a comprehensive overview of the child-robot interaction research landscape. Their work highlights the growing interest in studying children's interactions with robots, but points to the lack of research specifically focused on the under-three age group. This observation underlines the need for more targeted studies in this critical developmental period.

Taking the model of Baraka et al., (2020) as an example, which identifies seven dimensions that define a robot's potential as a social agent, we have chosen to focus on the most impactful characteristics for educational settings: appearance and social capabilities. The appearance of a robot, especially its level of anthropomorphism, strongly influences how children perceive and relate to it, often determining the level of emotional and social engagement it can elicit (Di Dio et al., 2020a, 2020b, 2020c; Manzi et al., 2020a; Miraglia et al., 2023). Social capabilities, which include the robot's ability to interact through gestures, sounds, or speech, are equally crucial in shaping the quality of interactions and encouraging behaviors like imitation and role-playing (Marchetti et al., 2018, 2022; Riva & Marchetti, 2022). While the broader model offers valuable insights into robot design, our study concentrates on these two dimensions particularly important for child-robot interaction in educational contexts.

Drawing on developmental psychology theories, particularly those of Piaget and Vygotsky, our research aims to understand the influence of robot design on cognitive and social development in early childhood. We investigate how different degrees of anthropomorphism in robots affect children's play, learning processes, and group dynamics. Using observational methods and qualitative analysis, we provide a detailed view of how very young children perceive and interact with robotic artefacts, capturing their spontaneous behavior in naturalistic settings.

## Objectives

This exploratory study investigates how children aged 18 to 36 months engage with robots during their playtime in a nursery setting, exploring the affordances of objects, particularly their socio-material characteristics (Cattaruzza et al., 2024; Iannaccone et al., 2018; Manzi et al., 2020a, 2020c). The primary objective is to investigate how children engage with robotic artefacts that have varying degrees of physical anthropomorphism and to identify the nature of the relationships that children form with both the robots and their peers as well as the adults in the context of free play. We aim to explore into the socio-material characteristics of these robot interactions. By comparing two different types of robots—one with a high level of human-like features and the other with a more mechanical appearance—we seek to uncover how their physical characteristics influence and potentially transform children's group play activities. This exploration is based on a socio-material perspective, emphasizing the interplay between social interactions and material attributes of the robots (Manzi et al., 2018, 2020b). In addition, our study intends to observe and analyze the direct and indirect effects of the robots on children's cognitive and social development. This includes investigating how the presence and design of these robots influence children's behavior, interaction patterns, and learning processes within a naturalistic play environment. From an educational perspective, this study aims to provide insights into how robotic tools can be utilized to support cognitive and social development in early childhood. By observing and analyzing children's interactions with these robots, we seek to identify ways in which these technologies can foster skills such as symbolic thinking, imitation, and collaborative play. Our findings are intended to inform the design and implementation of robots as effective educational tools that can enhance the learning experiences of young children within naturalistic play environments.

## Methods

### Participants

The present study involved 25 children aged between 18 and 36 months from two kindergartens in the province of Milan (Italy), two sections per school (see Table 1 for more details). Parents were given detailed information about the experimental procedure, the tasks, and the materials used during the experiment. The parents then gave their written consent. The research was approved by the local Ethics Committee of the Università Cattolica del Sacro Cuore, Milan.

### Robots

We used two social robots, Pixy and Idol, designed to be suitable for children aged 18–36 months, each with a different degree of physical anthropomorphization, as shown in Fig. 1. Pixy, characterized by a mechanical appearance, embodies a machine-like design featuring tracked wheels for mobility and a screen that portrays facial attributes, with two blue circular shapes representing eyes. Despite its predominantly mechanical form, Pixy contains certain anthropomorphic elements, such as communication sounds and words (e.g., "bye, bye"). In addition, it can be fitted with plastic cubes on its top that can be used to activate specific behaviors, such as navigating around obstacles. Conversely, Idol has a greater degree of anthropomorphism compared to Pixy. Resembling an astronaut with a helmet and a white body, Idol has a more human-like facial structure, complete with a screen that, when activated, displays two expressive eyes that can change shape to convey emotions. In particular, Idol enables interaction through verbal communication, incorporating speech recognition and reproduction software, as well as sensors located on its head and arms to enhance engagement.

**Table 1** In this table are reported the number of children for each nursery school sections and the mean age in months

| | Section 1 | Section 2 | Section 3 | Section 4 |
|---|---|---|---|---|
| *N* | 9 | 6 | 5 | 6 |
| Mean age (months) | 33.5 | 25.6 | 27.5 | 31.1 |

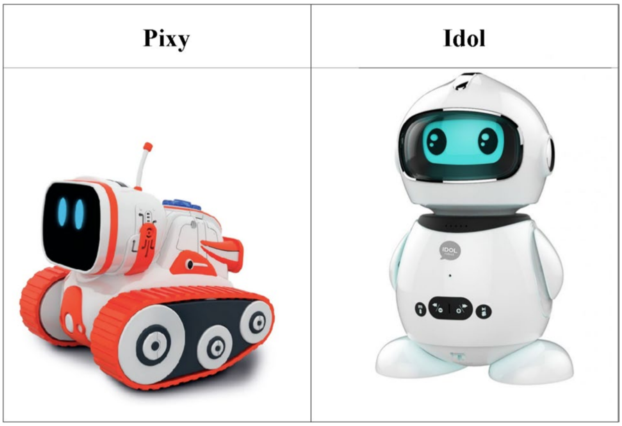


**Fig. 1** Images of the two robots used for the study

Both robots used in this study, Pixy and Idol, were pre-programmed with their default interactive modes. As they are not open source, we did not modify their programming but utilized the standard behaviors embedded within each robot.

## Procedure

During the activities at the childcare facility, the researcher, hereafter referred to as "Exp," was introduced to the children by their group teacher (hereafter referred to as "Teacher"). To initiate the familiarization process, a 30-min introductory meeting was held with the children. Exp then conducted four 30-min sessions (two for each robot, Pixy and Idol) to demonstrate the functionality of these two robots. In particular, Exp showed how Pixy could be switched on and move around the environment by placing cubes in a tray. Idol, on the other hand, was able to talk, express emotions, and react to the touch of certain sensors. Sitting in a circle with the Teacher, the children watched these demonstrations, taking turns and experimenting with the robots to fully understand their operation. Through this phase, the children had the chance to witness the robots' agency—their capacity to act with the environment (Jackson & Williams, 2021). The subsequent phase involved the integration of the robots into the children's classroom environment through four additional free play sessions, each lasting 30 min (two sessions for each robot). The robots were placed among the children's toys so that they could freely integrate them into their play activities. During these free play sessions, both the Teacher and Exp were present within the classroom to observe and facilitate as needed. In order to fully document the children's activities comprehensively, all sessions were videotaped using two fixed cameras positioned to capture the totality of the children's interactions. Cameras, while initially a source of curiosity for the children, quickly became familiar objects as they were routinely used to document daily activities in the nursery.

## Qualitative analysis of children's interactions with robots

In our study, we used a qualitative approach to analyze the interactions between children and robots during free play sessions in a nursery setting. This analysis focused exclusively on the transcribed content of the free play sessions of the four groups of children, involving two sessions per robot. As a result, we examined a comprehensive set of 16 videos, totaling 480 min of recorded child-robot interactions. The first step in our analysis was to immerse ourselves in the data, following the recommendations of Braun & Clarke, (2006) and Giuliani, (2015). This involved an unstructured exploration of the material, which led to a meticulous transcription process. The transcriptions included all forms of interactions, providing a detailed account of each 30-min video segment. The use of Nvivo 20.7 software facilitated this process, allowing for efficient cataloging and comparison of significant text segments. To ensure accuracy, the transcriptions underwent a process of cross-checking, which resulted in a high level of agreement between the researchers. We then proceeded to classify and label the interactions. This process was collaborative, involving discussions within the research team, leading to adjustments and the identification of macro-categories. Our analytical framework drew on two reference models: interpretative phenomenological analysis (IPA), as suggested by Smith et al., (2021), and interaction analysis (Jordan & Henderson, 1995). The IPA method helped us derive labels and categories from the transcripts, while interaction analysis offered a nuanced understanding of human activities in these interactions. Based on this process of analysis, we have identified six macro-categories (i.e., units of analysis; UoA). The UoA is detailed in Table 2.

## Results

### Sensorimotor explorations

The term "sensorimotor exploration" refers to the process of acquiring knowledge about objects through both direct perception and manipulation, as proposed by Piaget, (1929). In the case of the children's interaction with the two robots, their activity was characterized by a form of sensorimotor exploration of the robotic artefacts. The introduction of these novel artefacts stimulated the children's innate curiosity, leading them to physically explore the different components of the robots. This type of activity was not influenced by the degree of physical anthropomorphization of the robot, as evidenced by examples in Table 3 (see also Fig. 2). The children initially perceived the two robots as unfamiliar objects, and their exploration was aimed at discovering the limits and possibilities of these robots for integration into their play activities.

**Table 2** Units of analysis (UoA) identified through the analysis of transcripts of free play sessions

| UoA |
|---|
| Sensorimotor explorations |
| Sociomaterial interactions |
| Symbolic interactions |
| Peer imitation |
| Symbolic game |
| Collectives activities |
| Role and function of adults (Teacher and Exp) |

**Table 3** Examples of sensorimotor explorations of the two robots, Pixy and Idol

| Pixy | Idol |
|---|---|
| N. turned the Pixy, examining the various sides of it. [sect. F, 07.05.21] | E. picked up the Idol again and kept turning it over. [Sect. F, 28.05.21] |
| N. was sitting with her legs outstretched, holding the Pixy, turning it over, and trying to remove a covering. [sect. F, 11.05.21] | A. continued to turn the Idol in his hands and watched the movement of the levers under its feet as they moved in and out. [Sect. D, 09.07.21] |
| A. turned it over, touched the feet, keys, and hands, and then went towards the Exp for asking something [sect. R, 25.05.21] | H. turned the robot in his hands. He touched the levers under the feet of the Idol robot. H. lifted the robot by the feet and carried it into the air. He took the robot's head in his hands and stared at it. H. turned the robot around, looked at the feet, and observed the levers. He turned the robot again in his hands several times, also touching the rear lever. [Sect. E, 24.06.21] |

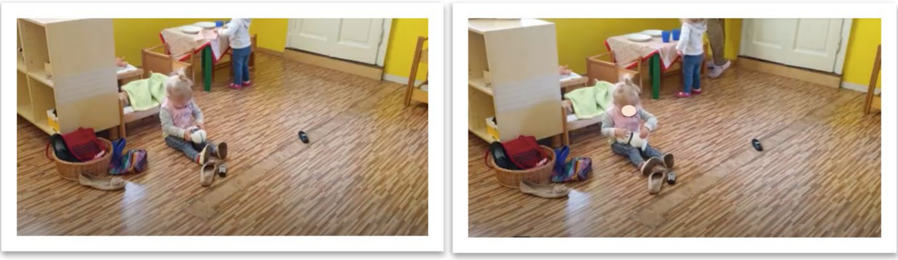

**Fig. 2** Examples of sensorimotor exploration of the robot

## Sociomaterial interactions

In the context of our study, the concept of sociomaterial interactions plays a crucial role in understanding how children engage with robotic artefacts. These interactions go beyond mere sensorimotor exploration and include activities in which children operate the robots as demonstrated by the Exp. The distinct sociomaterial characteristics of the robots, derived from their design and functionality, evoke different modes of interaction among the children. The introduction of robots into the nursery environment, which are distinct from routine objects, captured the children's attention and changed their usual patterns of activity. This change in children's usual context has made robots not only objects of curiosity, but also focal points for new forms of activity. The children's responses to the robots varied depending on their design, highlighting the interplay between the material aspects of the robots and the children's social environment. The mechanical robot (i.e., Pixy) was often approached with familiarity and incorporated into play almost immediately. In contrast, the robot with more anthropomorphic features (i.e., Idol) intrigued the children due to its unique form and capabilities, leading to a different kind of exploratory behavior. This observation aligns with the concept of sociomateriality, which considers the blend of material elements with social ones (Cattaruzza et al., 2024; Iannaccone et al., 2018, 2020; Manzi et al., 2020a, 2020c). Our findings suggest that when children interact with robots, they do not simply engage with them as inanimate objects. Instead, they actively participate in shaping these interactions, influenced by the robots' physical characteristics and their own social and cultural contexts (see Table 4). The interactions with the robots also revealed a range of unconventional ways in which the children engaged with them. These interactions often did not conform to the robots' intended functionalities but emerged organically from the children's exploratory and imaginative play. This phenomenon highlights the concept of affordance in the context of child-robot interaction, where children discover and create new ways to interact with the robots based on their perceptual and cognitive abilities (see Table 5 and Fig. 3). Notably, only one child showed a negative reaction specifically towards Idol, expressing fear and reluctance to engage with the robot during the free play sessions. However, it is interesting to note that the same child was willing to play with Pixy.

## Symbolic interactions

Through a close examination of Piaget's developmental theory, focusing on the relationship between signifiers and meanings, we have identified two categories in our analyses that can be related to deferred imitation and symbolic play, concepts as described by Piaget, (1929). During their initial encounters with the robots and the experimenter who introduced them, the children engaged primarily in sensorimotor explorations. However, when the children encountered the robots within the nursery setting, they exhibited various forms of imitation and symbolic play in their interactions with the robotic artefacts.

## Peer and robot imitation

An important psychological process of child-robot interactions is the imitation of peers and adults, as well as the imitation of robots (see Table 6). Children often imitated not only the physical actions but also the sounds and verbal expressions of the robots. The tendency to imitate peers in their interactions with the robots was particularly evident, showing a form of reciprocal and deferred imitation. This phenomenon crosses the boundaries of time and space, indicating a

**Table 4** Examples of sociomaterial explorations of the two robots, Pixy and Idol

| Pixy | Idol |
|---|---|
| K., still lying on his side with Pixy in front of him, removed the square and then puts it back on. K. turned it around to take aim and then used only his thumb to push the cube all the way down, which lighted up green. [sect. F 11.05.21] | K. held Idol close to his face and interacted with it by looking at the screen and listening to its words. [sect. F. 28.05.21] |
| N. took the Pixy and tried to use it putting the cube inside. N. did it by pushing it with one finger at the end, just like K. did, but it did noy make a sound right away. Then N. sat down on the floor, took the cube out, turned Pixy around, found the power switch, and moved it. It made the sound of greeting to turn on. N. took the cube, turned it between her fingers until she had a good grip, inserted it into Pixy, and pressed hard with one finger until the cube turned on. N. looked around at me and her companions. N. continued to press the cube because Pixy didn't start immediately. When N. let go, the robot began to move, but N. immediately took it back in her hand and proudly showed it to the teacher. Then N. tried again to press the cube. [sect. F 11.05.21] | E. examined Idol from the front and back and touched its head with his right hand, then stands in front of it. [sec F. 28.05.21] |

**Table 5** Examples of unconventional sensorimotor exploration of the two robots

| Pixy | Idol |
|---|---|
| A. is left alone to play with Pixy, trying to reattach a piece that has come off its head. Despite never succeeding, he starts playing with the piece, sticking it on his fingers for about a minute, and then goes back to trying to reattach it to the robot, alternating between the two activities. [sect. D, 22.06.21] | Dy. goes around the entire room shaking the Idol, then places it on the kitchen cabinet. The Idol swings back on itself once, and Dy. repeats the movement before starting to run away, shaking his arms and ending up on the pile of mattresses in the corner. Dy. returns to the kitchen cabinet, picks up the robot again, makes it talk, and runs around the room. He stops in the middle, always turning it over, occasionally placing it under his arm and stroking its head, but then still holding it. [sect. D, 9.07.21] |
| L. sits on the ground, first passes the Pixy robot over the machine track, then tries it on the grey basket he has turned upside down and starts moving the robot over it again. [sect. E, 9.07.21] | Al. sits in front of the Idol robot, lays it down, and observes its feet. [Sect. R, 25.05.21] |
| G. holds Pixy like a little car, with his left hand on top he drives it, even though it is on and could move autonomously. G. picks up the robot and starts to move it back and forth, then towards himself. He turns towards Exp and smiles, moving forward (always around Exp. and G). [sect. R, 8.06.21] | L., however, doesn't let go of Idol and places it on a shelf by the kitchen cooker. They stand looking into each other's eyes for a while, then he lays it down and turns to the toy cars. He preens one of them and runs it over Idol as well, after the toy car has passed over the robot's apron and leapt up to the sink. L. leaves them and returns to the robot, putting it back in its standing position. He dangles it over his hands and hears the robot say, "You tickle me." L. then puts the Idol robot back in its original place where he found it at the beginning of the day. As he carries it to the shelf, he says "THANK YOU," then sets it down, occasionally letting go of it, looking at it, and standing with his arms at his sides as if in satisfaction. As he leaves, L. turns to look at the robot and then back at the Teacher. [Sect. R, 25.05.21] |

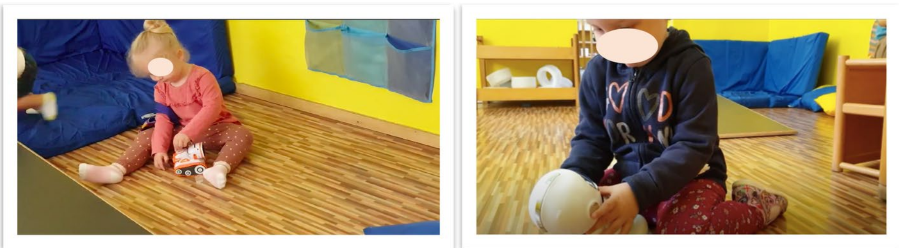

**Fig. 3** Example of social-material interactions with the Pixy and Idol robots

deeper level of cognitive processing and social learning among children in the group. Moreover, the children attempted to replicate several actions demonstrated by the Exp during the familiarization of the robots. This indicates their capacity for observational learning and their ability to translate observed actions into their own interactions with the robots. The variation in their success in these attempts highlights the different stages of development and understanding

**Table 6** Examples of imitation of robots, adults, and peers

| Pixy | Idol |
|---|---|
| Robot | |
| When Pixy said, 'Bye Bye', K. and O. echoed it. [Ref. 6, Sect. F, 11.05.21] | When Idol said, "Shall we become friends?" L. echoed by saying "Friends." [Sect. F, 25.05.21] |
| Adult | |
| N. tried to get Pixy onto his hand, as shown in the robot's presentation meetings by the Exp two weeks earlier. When it very slowly climbed onto his hand, N. said "HAND" with a smile. [Sect. F, 11.05.21] | G. asked the Exp how to operate the Idol's songs. [Sect. R, 25.05.21] |
| Peer | |
| S. picked up Pixy and made it move on the floor, holding it as G. had previously done. [Sect. R, 8.06.21] | A. got up and carried Idol like a doll, sat down like D., put his other hand in his mouth, and laughed a little to emphasize that he was imitating D. [Sect. D, 6.7.21] |

among the children. Another fascinating observation was the children's engagement in symbolic play with the robots. This form of play, influenced by their interactions and observations of their peers, underlines the importance of peer imitation in cognitive and social development. Through symbolic play, children extend their understanding of the world by experimenting with different roles and scenarios that contribute to their overall development. These aspects of imitation reveal the role of peer dynamics in shaping children's interactions with robots and highlight the potential of robotic artefacts to facilitate cognitive and social learning in a group setting.

## Symbolic game

The study of children's interactions with robots in our research has also delved into the realm of symbolic play. This aspect of child development is particularly noteworthy as it reveals how children integrate robots into their imaginative play, assigning them roles and scenarios that extend beyond the robots' functional attributes (see Table 7). In the realm of symbolic play, we observed that children's engagement with the robots was significantly influenced by their physical characteristics. The robot with a more mechanical appearance was often incorporated into play as a vehicle or machine, reflecting its design and functionality. Children were seen to use it in ways that mirrored its interactive-mechanical features, creatively adapting its capabilities to fit into their imaginative scenarios. Conversely, the robot with more human-like features elicited a different type of symbolic play. Children often treated this robot as a "human" character, engaging with it in scenarios that mirrored human actions and social interactions (see Fig. 4). This difference in play styles underscores the impact of the robots' physical anthropomorphization on children's perception and engagement in symbolic play. The difference in symbolic play between the two types of robots also highlights the developmental significance of such interactions. Symbolic play is a crucial component of cognitive development in early childhood, enabling children to explore and make sense of the world around them. By engaging in symbolic play with the robots, the children not only learned about the robots but also developed important cognitive and social skills such as creativity, problem-solving, and empathy.

**Table 7** Examples of symbolic play with the two robots

| Pixy | Idol |
|---|---|
| L. gathered more pots and pans, making Pixy jump from the colander to the pots and then into the empty sink, while K. and Z. continued their interaction with the cutlery. L. tried placing Pixy on the edge of the sink, consistently accompanying his actions with vocalizations of "ooo." [Sect. F, 07.05.21] | G. served the food cooked by A. and G. to both the Exp and the robot Idol. [Sect. R, 25.05.21] |
| L. went to the kitchen sink with a wooden plank and positioned Pixy half in and half out of the sink. He then picked up Pixy again and placed it on the slide made with the wooden board inside the sink. L. moved Pixy with one hand, accompanying its movements with "OOO OOO" vocalizations, varying the pitch based on Pixy's movements. [Sect. F, 07.05.21] | G. played with the robot Idol by laying it on the cot with a blanket. [Sect. R, 28.05.21] |
| Z. stacked all the pots on top of Pixy while it was in the sink, held by L.'s hand, which made it move up and down. [Sect. F, 07.05.21] | C. placed the robot Idol on the table and tried to feed it with a pot placed on top, saying "yummy." C. then took a spoon from a bowl and tried to feed the robot, repeating "yummy" multiple times. Subsequently, C. used a ladle to attempt to feed the robot and returned to using the bowl with the spoon. [Sect. E, 24.06.21] |
| L., alone at the kitchen game with Pixy, ran it over several shelves, always commenting with "OOO." [Sect. F, 07.05.21] | L. picked up Idol and took it to the dining table, seating it on a blue chair and placing a glass in front of it. [Sect. F, 28.05.21] |

**Fig. 4** An example of symbolic play with the Idol

## Collectives activities

The exploration of collective activities in the context of child-robot interaction highlights the nuanced dynamics of socialization and group behavior among children in a nursery setting. The presence of robotic artifacts, serving as significant objects of interest, elicited a range of social behaviors and interactions within the group, providing a unique lens through which to observe child development in a collective context.

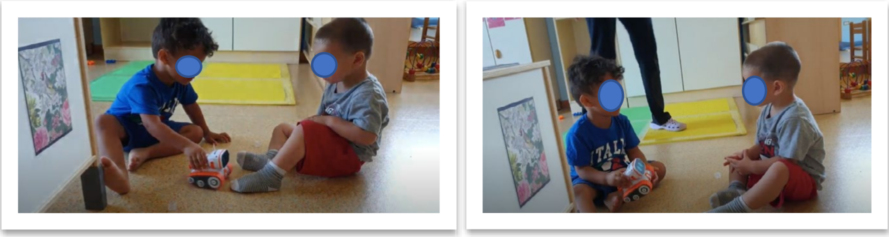

**Fig. 5** Two children in a group dynamic with the Pixy robot

**Table 8** Examples of the mediation role of the robots

| Pixy | Idol |
|---|---|
| B. sat down to play with the robot, and C. sat on his right. C. asked, "Can you play?" Exp confirmed, "You can play a little." Then F. arrived with a bowl and spoon in his hand and walked away. F. sat there watching, with Exp sitting at his side. The teacher told C. to give the robot a kiss and then passed it to another child. [Sect. D, 22.06.21] | N. and L. took Idol to the wooden kitchen and place it on the cooker. N. wanted it all to himself and as so hostile towards L. that he pushed G., prompting G. to intervene and make peace. [Sect. F, 25.05.21] |
| Dp. was sitting with Pixy on her lap, facing her, watching and listening. When Pixy emitted laughter, Dp. smiles and looked up at Exp. A. was sitting in front of her, waiting. Dp. handed the robot to A., who thanked her and gave it back. [Sect. D, 22.06.21] | Al. kneeled down, reached towards the Idol, then snatched it from M.'s hand, saying "me, me." M. groaned and in turn stretched out his hands towards the robot. Exp sat down next to the children and told Al. to give the robot back to M. Al. responded, "I wanted to use it again." [Sect. E, 9.07.21] |

The introduction of robots into the play environment often altered the course of group activities, influencing children's behavior and engagement patterns. The socio-material characteristics of the robots played a central role in this dynamic, influencing how the children interacted with each other and with the artefacts. This observation aligns with the work of Gfeller et al., (2021), emphasizing the importance of understanding children's ability to navigate social contexts and engage in collective activities. Our findings revealed instances of competition and collaboration among children when engaging with the robots (see Fig. 5). These interactions varied from contentions over robot usage to cooperative endeavors in shared play, reflecting the diverse social dynamics within the group. Such behaviors underscore the role of educational robotics in mediating social interactions among young children (see Table 8). Notably, the study observed a progression in the children's behavior over time, with initial contentions giving way to more structured and peaceful interactions (see Table 9). This change could be attributed to an increased familiarity with the robots and the environment, echoing the concept of the "uncanny valley" effect described by Mori, (2012). In our use of "echoing the uncanny valley," we specifically refer to how the effect is initially triggered by the robots' appearance, which can cause discomfort when they look almost but not entirely human-like. However, as the children became more familiar with the robots through repeated interactions, this sense of unease diminished, indicating that experience can help soften the impact of the uncanny valley effect. Thus, children gradually adapted to the presence of the robots, learning to

**Table 9** Interaction between the teacher and children

| Pixy | Idol |
|---|---|
| The teacher, without moving, intervened and suggested to S. to tell Al. that she wanted the robot. S. then said "iaia iaia" (which was how she called her sister). The teacher asked Al. if she was ready to leave the robot, and she said no. In response, Al. detached herself from the robot, and her sister took it. Al. noticed the theft and became angry, crying and stamping her feet. The teacher arrived to comfort Al., and S. got up with the robot and moved to the middle of the room. [Sect. R, 25.05.21] | C. walked around the room and approached the Teacher with the robot in his arms, singing. The Teacher said, "Congratulations, robot, what a beautiful song," and the robot replied, "Can you repeat that, please?". C. walked on the mats and then approached the Teacher, pressing the buttons on the robot's belly. The Teacher said, "Song, he said song, let's see. He no longer speaks." F. wandered around the room. The robot made sounds, and the Teacher danced while sitting, inviting F. to come closer to listen together. F. looked at the robot and smiled. F. sat on the floor. The Exp sat on the floor and interacted with F. Then, C. got up and walked around the room with the robot in his hand. [Sect. E, 24.06.21] |

navigate the social environment with these new elements. Furthermore, the research highlights the significant influence of adult facilitation in these collective activities (see Table 10). The presence and guidance of teachers and researchers was crucial in mediating interactions and ensuring inclusive and constructive engagement with the robots. This observation is consistent with previous studies (Jung & Hinds, 2018; Rabb et al., 2022), which emphasize the role of adults in shaping children's experiences and interactions in learning environments.

## Role and function of adults (Teacher and Exp)

Another important element influencing the interactive children's dynamics with robots is evidently the presence and participation of the Exp in the activities. Moreover, also the role of children's attachment should not be underestimated either (Lisonbee et al., 2008; Vandenbroucke, 2018) which influences routines and responses to the new objects (Howes & Hamilton, 1992) (see Table 11). The role and function of the adults (both Teacher and Exp) emerged prominently in supporting the regulation of emotions during the children's interactions, managing play shifts, and serving as a point of reference for operating the robots (even after the demonstration

**Table 10** Examples of group dynamics also include situations of cooperation

| Pixy | Idol |
|---|---|
| S. picked up Pixy and Re. became angry, screamed, and picked up the small piece, lifting it up. S. made Pixy walk by inserting the small piece; the operation is successful, and Re. was happy | A song started playing from the robot and Dp. began to dance. Dp., initially kneeling with the robot in his hand, then got up and started dancing too. Dp. began by jumping and waving his arms, then moved around the room together with Dp. He run to turn the robot back on, saying "Hello, shall we become friends?" D. also arrived and they looked at it curiously. [Sect. D, 06.07.21] |

**Table 11** Examples of the role of the Teacher and the Exp in the children's play interactions

| Pixy | Idol |
|---|---|
| *Teacher* | |
| *The Teacher, still sitting in the same place, said "now it's Z.'s turn", "come on Z. now it's your turn." Z. left his game, went towards the Teacher who in the meantime told him that it was his turn to play with Pixy and to go and get him. O. got up from the table when Z. arrived; O. held Pixy with two hands off the table, Z. picked him up and O. did not resist. [Sect. F 07.05.21]* | *N. and L. take Idol to the wooden kitchen and place him on the cooker. N. would like to have him all to himself and is hostile towards L., so much so that he urges Exp to intervene to make peace. Having obtained the robot, L. drops it on the floor for a moment, probably surprised that it is still in one piece. Picking up Idol, L. continues to place it on the kitchen and then places it on the sink and then on the edge of the sink and falls and exclaims OOO L. picks it up holds it by the neck and looks at its face then stands up and places it back on the kitchen and goes to the stove and finally to the fridge, kisses it and watches the rocking movement the robot makes. [sez F.26.05.21]* |
| *Exp* | |
| *N. asked Exp. for help to turn on the Pixy robot (N. said sadly "It doesn't go"), Exp. then fixed it. [Sec F 11.05.21]* | *The children gathered around waiting for the robot Idol to appear. Exp. asked them "what do you want from me?" They replied "Idol", but Exp. replied I don't have it today. [Sect. F 25.05.21]* |
| *The framing shifted to the left side of the room, where Al. maneuvered the robot on a table, then picked it up and asked Ed2 "like this?" and put in and took out the cube that operates the robot. Ed2, sitting a little way away from the table, replied "I don't know, I can't see from there", Al. then approached, repeating "like this?", putting in and taking out the cube, and showing her the robot. Exp. said "yes", and Al. sat down on the floor in front of her. [Sec E, 09.07.21]* | *N. ran to Exp. to say hello; they all went to Exp.; N. went to Exp. and asked if he had brought Pixy robots. [Sec F 07.05.21]* |
| *L. ran after Exp.; L. made a small diversion and went towards Exp. to be hugged; L. returned the hug and then ran away and went towards his companions. [Sect. F 11.05.21]* | *L. approached the unattended Idol robot and exclaiming "Oh, Wow" handed it upwards in Exp's direction. She asked him where he should put it and L. made her understand that she should hold it. [Sect. F 28.05.21]* |
| *K. looked for Exp. and brought Pixy to her to make it work; Exp. returned it to her and K. held Pixy with her right hand and with her left hand tried to move the stick. She turned again to Exp., with interlocutory noises, Exp. answered "let me see", ducked down to make contact with her gaze and moved the stick; Pixy made the switching sounds; G. returned the robot to K. [Sect. F 07.05.21]* | *The children began to approach Exp. (O. hugged her and sat on her lap). [Sec F 25.05.21]* |

and familiarization sessions). Children who had a strong bond with their educators appeared more willing to approach and engage with the robots, using the presence of a trusted adult as a secure base for exploration. This supportive relationship likely provided the children with a sense of safety and confidence when interacting with the unfamiliar robotic artifacts in their environment. Conversely, children who had weaker bonds with the educators tended to exhibit more cautious behavior, maintaining a greater physical distance from the robots. These findings underscore the importance of the educator's role in mediating the child's experience with technology, highlighting how the quality of this relationship can facilitate or hinder children's engagement with robotic artefacts. The other adult, the Exp, who introduced the robot into the everyday space of the nursery, is identified as an expert on the robotic object and therefore asked about its operation and/or use. The more "technical" role of the Exp changes over time to that of a reference adult.

## Discussion and conclusions

The main aim of the study was to explore how children aged 18–36 months interact with robots that differ in their level of anthropomorphism within an educational setting (i.e., nursey). Specifically, we sought to understand whether the physical and interactive characteristics of the robots would influence the nature of the children's play behaviors and their social engagement with these robotic artefacts. Our results revealed that the degree of anthropomorphism in the robots had a significant impact on children's interactions. Idol, the robot with more human-like features and interactive capabilities, prompted higher levels of social engagement, symbolic play, and imitation behaviors. Children often treated Idol as a social partner, engaging in role-playing. In contrast, Pixy, which had a more mechanical appearance and limited interactive features, was primarily explored through sensorimotor activities. Children interacted with Pixy more as a tool or object, focusing on its movement and mechanical functionalities rather than engaging in social or symbolic play. In terms of collective activities, Idol fostered collaborative play and group interactions, encouraging children to engage with each other in shared activities. In contrast, the design of the Pixy resulted in more individual play, with less emphasis on social engagement. Regarding the role of the adults, the presence of educators and the experimenter was essential in guiding the children's interactions, enhancing their engagement, and facilitating a more structured exploration of the robots.

By studying child-robot interactions in a quasi-natural context, we have gathered valuable insights for both theoretical conceptualization and practical educational applications. In line with a significant body of literature on children's play, a common thread in the situations observed in our research is the ease with which children seamlessly integrate mechanical objects into complex and socially intricate scenarios. This innate ability of children to perceive the two robots as play partners emerges effortlessly and offers critical insights into fundamental aspects of human psychological experiences within the sociomaterial world. Overall, the results show that the sociomaterial characteristics of robots' influence children's activities: the way children explore the robotic artefact is related to its material and anthropomorphic characteristics.

There are many explanations for this phenomenon, which can be traced back to classic psychological concepts such as Piaget's concept of animism (1929). Undoubtedly, the animistic element in children's interactions with robots plays a crucial role in establishing a playful connection with these non-human companions. This humanization of artefacts is likely to tap into fundamental features of human psychological development that are particularly evident in children, a concept also emphasized by Winnicott, (1951) in his theories of child development.

In the field of social robotics, this perspective is of paramount importance. Indeed, the ability to attribute anthropomorphic characteristics to a robot depends on a mix of physical appearance and behavior that encourages this attribution, as suggested by Marchetti et al., (2018). It is interesting to note that the relationship between children and robots is inherently bidirectional, as highlighted by Cagiltay et al., (2022), among others. Their research shows how caring for an interactive toy or robot can foster stronger bonds, improve psychological well-being, and facilitate various forms of learning.

While our observations have revealed clear shifts in the nature of children's interactions with the two robots based on age and anthropomorphic characteristics, what stands out most is their innate ability to establish a basic empathic connection (Manzi et al., 2020b, 2020d, 2023). Nevertheless, it is important to note that significant age-related differences emerged, particularly in the mode of interaction. Our observations revealed different ways in which children engaged with these complex technological objects, in line with different modes of exploration and communication characteristic of children. Some showed primarily sensorimotor exploration, in line with Piaget's framework of sensorimotor intelligence. In more advanced stages of development, children form interpersonal relationships with robots, viewing them as potential social partners (Di Dio et al., 2020a, 2020b). In this context, what we term "animistic" competence emerges, with children displaying careful and precise attribution of coherent communicative and interactive functions to non-human partners within the play environment. This is consistent with the observations in social robotics, where children frequently attribute beliefs, intentions, desires, and mental states to objects and artefacts, a phenomenon referred to as robot anthropomorphism (Di Dio et al., 2020a, 2020b, 2020c; Manzi et al., 2020a).

In the field of educational robotics, where robots are used in educational and training settings, the issue of anthropomorphic projection is closely linked to children's beliefs about the artifact and the establishment of trust (Di Dio et al., 2020a; Peretti et al., 2023). However, the feeling of familiarity that a robot can evoke is not solely based on physical appearance but is also shaped by the type of interaction. In fact, the ability to attribute anthropomorphic characteristics to a robot results from a combination of physical appearance and behavior that encourages this attribution, as pointed out by Marchetti et al., (2018). From a different perspective that complements these findings, Pentzold & Bischof, (2019) introduce the concept of collective affordance, emphasizing that the relationship between humans and non-human entities is significantly influenced by the interaction context. This highlights the co-creation of multiple affordances within a socio-material framework.

In essence, if the physical properties of technologies have a socio-material component, it becomes crucial to consider the types of operativity and agency associated with these agents. The distinction between human agency and technical agency becomes less clear-cut when we acknowledge that technologies often take on agency roles and participate, alongside human agents, in shared situated actions (Pentzold & Bischof, 2019).

In our observations, two essential elements help to explain how children appropriate robotic technology: First, the construct of trust develops in the micro-context of learning as children gradually build relationships with anthropomorphic artefacts, providing cognitive and affective opportunities for intersubjectivity (Di Dio et al., 2020a). Second, the mediating function of such technology in a collective play and learning context is pivotal. The introduction of anthropomorphic technology does not merely create benefits within the learning construct; its attractiveness and limitations play a central role in shaping and enhancing or detracting from learning situations.

This underlines the need for technology to be purposefully designed to mediate and encourage intersubjective acts of meaning-making. Design should take advantage of the unique opportunities offered by technology, rather than attempting to replicate the support for learning that can be achieved by other means or forcing technology into roles for which it is not well-suited (Suthers, 2006). This scenario requires a dynamic perspective in education that takes into account the potential transformations induced by advanced technologies like robotics. Moreover, the design of learning contexts supported by such technology cannot ignore the social and cultural conditions in which learning processes acquire meaning. In this study, we positioned robots as educational tools that actively engage young children in learning experiences through play, imitation, and social interaction. Our findings underscore the importance of the socio-material characteristics of robots, particularly their level of anthropomorphism, in shaping children's engagement and the quality of their interactions. Idol's human-like features, for instance, facilitated a higher degree of symbolic play and social engagement, suggesting that anthropomorphic design elements can effectively support cognitive and social development in early childhood settings. This emphasis on robot design provides a deeper understanding of how educational tools can be optimized to meet the developmental needs of young learners. By tailoring robot characteristics to encourage specific types of interactions, educators and developers can better harness the potential of these technologies to enhance learning outcomes. Additionally, from a Vygotskian perspective, robots as cultural artefacts play a transformative role in children's learning environments. As they become more integrated into daily life and educational contexts, robots have the capacity to reshape the ways children learn, interact, and make sense of the world creating at the same time, and precisely according to the characteristics of each of the robots, different types of learning spaces. Although the data examined so far do not allow definitive conclusions to be drawn in subsequent analyses, it seems plausible to think that in the relationship established between robots and children, conditions are created for potential learning (i.e., zone of proximal development) based on different types of helping relationships represented by the two robots. In particular, the more anthropomorphic robot seems to support the socio-emotional aspects of the relationships established in the learning situation. On the basis of the evidence gathered so far, one could imagine that the robot with less emotional characteristics tends to support more individualized relations to the task. We would thus be in the presence of two complementary learning areas that both benefit, in different ways, from the relationship to the robotic agents.

## Future research directions

Future studies should delve deeper into individual factors that might influence child-robot interactions. Assessing verbal comprehension and production using standardized tools like the MacArthur-Bates Communicative Development Inventories (MBCDI) and gathering information about the family environment could provide a more nuanced understanding of how language skills and external factors impact engagement with robotic artefacts. In addition, methods to assess children's perceptions and expectations about robots, even in very young age groups, could be beneficial. Since verbal expression may be limited in children as young as 18 months, alternative approaches like non-verbal cues or parent-reported assessments could help gauge how children perceive different robotic designs, offering deeper insights into their cognitive and emotional responses. Future research should consider replicating this study with homogeneous age-specific groups of children to explore how group composition influences child-robot interactions. By focusing on groups that share similar developmental stages, researchers could gain clearer insights into how age-related factors affect these interactions, ultimately leading to more tailored pedagogical approaches in early childhood education. Expanding on these findings by incorporating quantitative methods, such as measuring the duration and frequency of behaviors, would provide a more structured and data-driven perspective on child-robot interactions. Combining both qualitative and quantitative approaches could offer a comprehensive understanding of the factors that influence these interactions, ultimately contributing to the development of more effective educational tools for young learners. Additionally, future studies should include comparisons between children's interactions with robots and other non-living objects to better understand the unique role that robots play in educational contexts.

**Data availability** All data supporting the findings of this study are available upon request from the corresponding authors.



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*Current themes of research:*

Educational Robotics in the lifespan.

*Most relevant publications in the field of Psychology of Education:*

Sacco, F., Rossini, G., Manzi, F., Di Dio, C., Aquilino, L., Cangelosi, A., Raggioli, L., Massaro, D., & Marchetti, A. (2023, October). *An Antropomorphic Robot with ChatGPT for Learning Activities: The Teachers' Perspective*. In 2023 IEEE International Conference on Metrology for eXtended Reality, Artificial Intelligence and Neural Engineering (MetroXRAINE) (pp. 1166–1170). IEEE.

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*Current themes of research:*

Theory of Mind in typical and atypical development; Theory of Mind in human-robot interaction in a lifespan perspective; Educational Robotics and AI; Sociomaterialty; Autism; Argumentative process in children.

*Most relevant publications in the field of Psychology of Education:*

Sacco, F., Rossini, G., Manzi, F., Di Dio, C., Aquilino, L., Cangelosi, A., Raggioli, L., Massaro, D., & Marchetti, A. (2023, October). *An Antropomorphic Robot with ChatGPT for Learning Activities: The Teachers' Perspective*. In 2023 IEEE International Conference on Metrology for eXtended Reality, Artificial Intelligence and Neural Engineering (MetroXRAINE) (pp. 1166–1170). IEEE.

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*Current themes of research:*

Aesthetic perception and developmental psychology, with a particular focus on decision-making processes, psychology of religion in children, and human-robot interaction in a life-span perspective.

*Most relevant publications in the field of Psychology of Education:*

Sacco, F., Rossini, G., Manzi, F., Di Dio, C., Aquilino, L., Cangelosi, A., Raggioli, L., Massaro, D., & Marchetti, A. (2023, October). *An Antropomorphic Robot with ChatGPT for Learning Activities: The Teachers' Perspective*. In 2023 IEEE International Conference on Metrology for eXtended Reality, Artificial Intelligence and Neural Engineering (MetroXRAINE) (pp. 1166–1170). IEEE.

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*Current themes of research:*

Social interactions, Argumentation in children and Sociomaterial dimensions of learning processes.

*Most relevant publications in the field of Psychology of Education:*

Iannaccone, A., Cattaruzza, E., & Schwab, E. (2024). *Expériences sociomatérielles: Objets, interactions, espaces*. Alphil-Presses universitaires suisses.
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*Current themes of research:*

Theory of mind and typical and atypical development across the lifespan; economic decision making and mental states; trust and attachment; understanding of irony; aesthetic experience; child-robot interaction.

*Most relevant publications in the field of Psychology of Education:*

Manzi, F., Ishikawa, M., Di Dio, C., Itakura, S., Kanda, T., Ishiguro, H., Massaro, D., & Marchetti, A. (2023). Infants' prediction of humanoid robot's goal-directed action. *International Journal of Social Robotics, 15*(8), 1387–1397.
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Valle, A., Massaro, D., Castelli, I., Sangiuliano Intra, F., Lombardi, E., Bracaglia, E., & Marchetti, A. (2016). Promoting mentalizing in pupils by acting on teachers: preliminary Italian evidence of the "Thought in Mind" project. *Frontiers in Psychology, 7*, 1213.

Valle, A., Massaro, D., Castelli, I., Intra, F. S., Lombardi, E., Bracaglia, E. A., & Marchetti, A. (2018). *Experiences and results of the resilience programme for primary school teachers in Italy*. In Developing Resilience in Children and Young People (pp. 31–46). Routledge.

**Davide Massaro.** Research Center on Theory of Mind and Social Competence, Department of Psychology, Università Cattolica del Sacro Cuore, Milan, Italy.

*Current themes of research:*

Theory of Mind development, decision-making processes, cognitive biases, religious belief development, understanding irony in children, Theory of Mind in HRI.

*Most relevant publications in the field of Psychology of Education:*

Sacco, F., Rossini, G., Manzi, F., Di Dio, C., Aquilino, L., Cangelosi, A., Raggioli, L., Massaro, D., & Marchetti, A. (2023, October). *An Antropomorphic Robot with ChatGPT for Learning Activities: The Teachers' Perspective*. In 2023 IEEE International Conference on Metrology for eXtended Reality, Artificial Intelligence and Neural Engineering (MetroXRAINE) (pp. 1166–1170). IEEE.

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