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# From learning machines to teaching robots. Interaction for educational purposes between the Social Robot NAO and children: a systematic review

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**Abstract**

Interaction between social robots and children occurs today in a variety of environments, including schools, hospitals, and homes. This review aims to highlight studies that delve into this interaction in the educational settings, exploring the characteristics of the social robot NAO and how its features influence its relationship with children. A search was conducted on July 1st, 2023 in Scopus and PsychInfo. Inclusion criteria pertained to (1) typical development; (2) age range 4-12 years; (3) educational setting; (4) type of robot (NAO); (5) type of publication: peer-reviewed journal; (6) language: English; (7) research studies. Of the 116 results that emerged from the search, 92 were excluded, yielding 24 valid results. We classified the records into two categories, namely 17 results were included in the "NAO as an informational and educational tool" category and 7 in the "NAO as a relational agent" category. The first category considers all studies where social robots were used as tools for educational and informational support; these studies delve into topics related to the teaching of school subjects and personalized learning, with a specific focus on emotional education. In the second category, we encounter studies that explore the relationships between children and robots, with a primary emphasis on the phenomenon of anthropomorphism, the attribution of mental states, touch interaction, and the robot's caregiving abilities. Based on the present review, social robots like NAO emerge as potential resources to implement new forms of teaching and interaction within the educational context; however, more research is needed to design developmentally-tailored programs and child-friendly features.

**KEYWORDS:** NAO, Children, Interaction, Education, Learning.

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## 1. Introduction

Anthropomorphic robots are an increasingly widespread technology in educational settings, such as classrooms. They have evolved into a facilitating tool with significant results in promoting the learning process, due to their ability to motivate children and increase their curiosity (Goh et al., 2007). Human-like robots have been used to examine social interaction (Tanaka et al., 2007), develop language knowledge, motivate learning and goal achievement, reduce anxiety (Alemi et al., 2015), enrich pedagogical scenarios (Park et al., 2016), improve problem solving during lessons (Brown et al., 2013), and capture children's attention (Ioannou et al., 2015). However, considering the speed of technological development in the field of education, academic knowledge and understanding of how young children use and learn with these robots are still very limited. Despite the current relevance of the topic, there

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is still a limited body of research that has examined the effects of this educational interaction on children.
In this sense, the National Association for the Education of Young Children (NAEYC) has recognized the potential of technology and has also called for increased research to better understand the use of technology in educational contexts (NAEYC, 2012). To respond to this request, many authors explored the possibilities offered by humanoid robots, including NAO. In research focused on education, NAO is often used because of its features, such as its advanced multimedia system, including four microphones, two speakers, and two cameras, which make it highly engaging for children. Moreover, this allows the robot to perform various operations, including voice and facial recognition. Secondly, despite its advanced technology, it does not require extensive programming experience from the user. This is an added value for its use in educational contexts, where the robot might be used by operators without specific programming competencies. Finally, previous research has shown that children feel comfortable interacting with NAO and perceive it more as a peer than as a toy (Ioannou et al., 2015). Other findings highlight that children are more attracted to robots than books or CDs, which leads, in turn, to better learning outcomes (Woods et al., 2004). This result was mainly observed in language learning contexts (e.g., Georgieva -Tsaneva et al., 2023). The recent developments in social robots' design had a relevant impact in terms of the learning possibilities that help develop a close and personalized connection with the user (Feil-Seifer & Mataric, 2005). For instance, the newest robots can integrate instructional structures and establish unique relationships with individual students (Ramachandran et al., 2017). Moreover, each student can independently determine their level of education and communicate their learning needs to the robot (Chen et al., 2020).
However, the cognitive aspect of learning is not the only one. Studies concerning motivational strategies underline the importance of the affective dimension of learning; among these, Riggs et al. (2016) state that emotional development precedes cognitive development. Therefore, when programming social robots, especially those that interact with young children, aspects of emotional recognition should always be integrated with the specific language and cognitive skills of that age group. Indeed, social robots are capable of developing additional interactive features, including recognizing emotional responses, thus generating a differentiated motivational strategies and catering to the preferences, requirements, and needs of each child (Obaid et al., 2018).
In sum, within the developmental and educational contexts, the use of social robots may vary from offering a technological support to teaching to stimulating engagement and motivation in children. We, therefore, conducted a systematic literature review to provide an overview of the state of the art regarding its interaction with children, both in the instructional and in the psychological fields. The purpose of this systematic review is to provide an overview of studies conducted in the field of education that have explored various types of interaction while simultaneously offering a map of activities within an educational context involving NAO and children. To do so, we included studies that examined the child-NAO relationship from a learning and/or engagement perspective. The following section presents all the steps that led to the final results included in this review.

## 2. Materials and Methods

Based on the criteria provided by the PRISMA guidelines for systematic reviews (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009), a search was conducted on July 1st, 2023, in two databases, namely Scopus and PsycInfo, using the following keywords strings, "robot nao" AND "child*" AND "educ*" OR "interact*". One hundred and sixteen documents were identified in the databases. After removing duplicate records, the studies were screened based on seven inclusion criteria: (1) typical development; (2) age range 4-12 years; (3) educational setting; (4) type of robot (NAO); (5) type of publication: peer-reviewed journal; (6) language: English; (7) research studies. The inconsistencies were discussed by the team of authors. After this process, 62 records were excluded; the second exclusion phase was defined by a single criterion: 1) out of scope. In this phase, 1 record was excluded because it presents the development of a collaborative behavior controller for social robots without taking into account the children-robot interaction.
Therefore, the full-text of N = 24 eligible articles was accessed. After reading the full-text, all documents were deemed eligible for the current review (Figure 1).
The included articles described the functionalities exhibited by NAO and, consequently, the perceptions and reactions of children during learning activities, games, and explorations of these new technologies by tutors and researchers. To better understand the functionality of NAO in the educational context and its required features, as well as the issued related to it, we divided the included studies into two categories, namely 1) "NAO as an informational and educational tool", and 2) "NAO as a relational agent". The first category includes all research in which NAO was utilized as an educational and informational assistance aid; the second category includes studies in which it was employed as relational agent to be known through multimodal experiences.

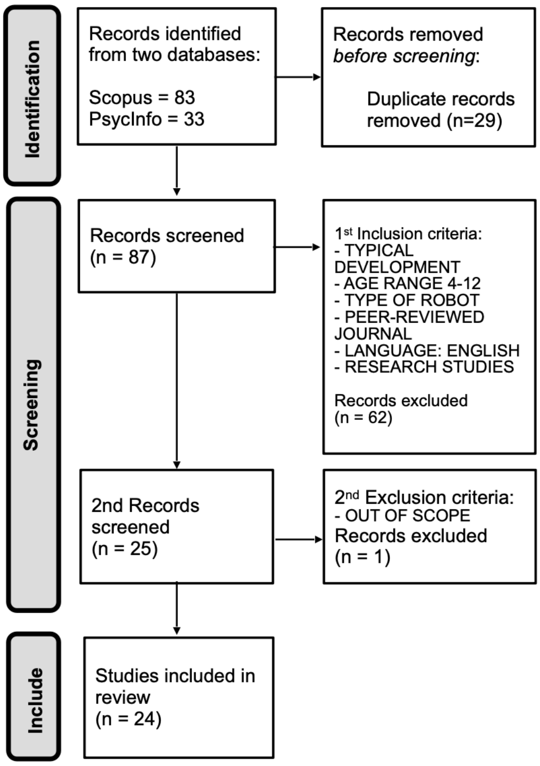


**Figure 1** - PRISMA 2020 flow diagram for new systematic reviews which included searches of databases.

## 3. Results

Regarding the "NAO as an informational and educational tool" category (Table 1), 17 results have been included.

The implementation of a NAO tutor with a personalization policy, conducted by Almousa and Alghowinem (2022), was measured on three behavioral outcomes of children: (1) academic knowledge (answer correctness), (2) attentional orientation and gaze direction, and (3) hesitation (time lag before answering). The results showed that children exhibit different behaviors and follow multiple learning paths during the interaction. Facial recognition, which allows the robot to learn and remember the child's name, has been highlighted as a central mechanism for attention and engagement. Indeed, the robot could detect if and when the child lost attention, assessing gaze and engagement zone, providing personalized feedback (e.g., calling the child by name) and repeating the question to regain attention. The authors underline personalization features, such as the ability of social robots to modify their expressiveness based on the perceived difficulty level for the child, as key to the child's greater engagement in educational tasks. Further research in this sense is recommended; for example, the social robot would gain a better understanding of where the child is facing difficulties and adapt accordingly, for example, by adjusting speech speed to that of natural human speech (Rossi et al., 2019)

So and Lee (2023) implemented a study in which NAO was used to create a playful and enjoyable interaction while teaching mathematics. The teaching of mathematical concepts related to lengths and their measurement was conducted through the social robot's presentation of slides, worksheets, and playing cards.

The results showed a greater effectiveness in learning when the interaction is perceived as friendly. NAO piqued the children's interest while delivering a concise mathematics lesson in the absence of a human instructor. Children exhibited a range of engagement cues, including head movements, facial expressions, bodily gestures, and verbal prompts. They identified the robot as a friendly learning companion and actively participated in the activities. However, integrating NAO into a formal setting proved to be challenging in the absence of trained personnel due to unexpected technical issues and constraints within the learning environment.

In the domain of math teaching, Alhashmi et al. (2021) studied the relational and learning outcomes of a robot teacher. Students expressed that they enjoyed the session with the robot and would have liked to dedicate more time to it. In terms of the learning experience, they reported better understanding of decimal numbers. The students thought the robot could not make mistakes because «he is electronic and knows many things» compared to the teacher. Teachers found that the robot lacked of empathy and would likely be unable to assist with tasks requiring social or emotional competence such as counseling, hugging a child, or promoting children's well-being.

Ponce et al. (2022) conducted a study aiming to explore the professional integration between educators and social robots in order to enhance students' attention capacity through a richer and diversified learning dynamic in different areas of the Mexican curriculum. Four different approaches were implemented: three in elementary schools and one in higher education. These approaches included the LEGO® robotics kit and the NAO robot for STEM (science, technology, engineering, and mathematics) teaching, the NAO robot for physical education (PE), and the PhantomX Hexapod. Participants were divided into two groups, with only one group interacting with the social robot to examine the difference in learning and exercise resolution in the following topics: sound propagation, the metric system, and fractions with whole numbers. The results demonstrated that students who interacted with NAO showed better outcomes in terms of attention retention, thus enhancing their overall performance during the lesson. Similarly, students preferred a robotic educational environment that reinforced the theoretical concepts previously taught in class (Ponce et al., 2022).

Levinson et al. (2021) demonstrated that social robots can be integrated into summer camps but also highlighted some critical issues. For instance, some children lost interest in the activities because of the robot's repetitive behavior. Moreover, the interaction with the social robot was not always smooth, and the authors found that its maximum and duration was close to seven minutes; they also considered the construction of mixed indoor and outdoor activities to be crucial.

Similarly, Crompton et al. (2018), while underling the new and extensive pedagogical possibilities and innovations in students' engagement provided by robots, noted that integrating them is often challenging due to teachers' lack of experience and knowledge on how to use them. Moreover, sometimes the social robot itself has limitations that inhibit its functionalities, which depend on unexpected events, resulting in failure to respond to a command given by a child or a teacher (Crompton et al., 2018).

Molenaar et al. (2021) conducted an experimental study investigating the effect of speech dragging in in Robot-assisted language learning (RALL). Specifically, the study aimed to delve into the convergence of voice pitch between NAO and children to examine potential differences in language learning. They found no interaction between the test phase (pre-test or post-test) and group (control or entrainment). Therefore, there is no evidence that entrainment in the robot can lead to a larger learning effect than otherwise.

In the field of music education, de Souza Jeronimo et al. (2022) compared two different robots, namely NAO and Zembo, in terms of children's preference after a guitar lesson delivered by the robot itself. Most children preferred Zenbo's cute appearance, facial expressions, and ability to express joy and sadness. NAO relies on voice pitch, body movements, and discreet lights in its eyes to express emotion. These lights may however make it difficult for users to recognize emotions and for robot designers to model them. In this sense, from a developer's perspective, NAO's emotional expressivity does not offer room for improvement, while Zenbo offers different facial expressions and the possibility of displaying animation (de Souza Jeronimo et al., 2022).

Still in the field of artistic activities, Neumann et al. (2022) studied the possibility of children developing a relationship with NAO during a drawing activity, in which the robot instructed the children. Some children talked to NAO but did not attempt the drawing task, while others performed the drawing tasks without verbally interacting. 83% of the children followed the robot's instructions and attempted to reproduce what was asked of them. The authors, in line with previous works (Baxter & Belpaeme, 2016; Baxter et al., 2017; Verhagen et al., 2019; Johal, 2020), point out the need to explore some individual variables that could affect children's interaction with social robots, such as personality traits. For instance, Baxter and Belpaeme (2016), based on a study investigating the extroversion/introversion continuum in primary school children, suggest that the application of personality assessments in a child-robot interaction should be conducted by also taking into account context-related variables.

Lopez-Caudana et al. (2022) conducted a study aimed at demonstrating NAO's ability to capture children's attention (being followed in the instructions and rules it provides) during a theoretical and practical physical education (PE) session. The study took place in primary school classes, where the levels of attention and motivation were analyzed. NAO was able to foster concentration, consequently leading to higher motivation and ultimately positively impacting PE participation and the adoption of a healthy lifestyle.

Rosi et al. (2016) explored the possibility of using NAO as an instructor and motivator in nutrition education at school. The presence of NAO in this intervention study did not increase knowledge of nutrition compared to "traditional" lessons. However, commitment and motivation of the child towards healthier food choices have been encouraged through the use of the robot.

Bono et al. (2020) studied the interaction between a child and three storytelling robots depicting a bullying scenario. The narrator was portrayed by NAO, while a Pepper robot played the bully, and another robot played the protagonist, i.e., the victim. The narrator, calling the children by name, invited them to give advice to the victim, in order to establish affiliation between the child and the robot. Children showed appreciation for storytelling through humanoid robots, even more so because they were programmed to express the internal states of the characters. Interestingly, users showed empathy also towards the bully (Bono et al., 2020). Some critical issues concerned the construction of the story dynamics and its duration, the number of scenes, and the (sometimes sparse) interaction among the characters.

With the aim of contributing to the growing field of affective robot tutors, Imbernón Cuadrado et al. (2016), developed ARTIE (Affective Robot Tutor Integrated Environment), a platform useful to identify emotional states. The authors integrated an educational software for primary school children with a component that identifies the emotional state of students interacting with the software and the driver of a tutor robot that provides personalized emotional pedagogical support. Despite the simplicity of the prototype and the involvement of only two children, the authors concluded that the humor of the robot is a motivating factor and the correct parameterization of the pedagogical intervention is essential. Moreover, it is necessary to understand what in the intervention sequence can increase the participant's difficulty; another element that can cause much frustration to the students is the misidentification of cognitive-affective states (Imbernón Cuadrado et al., 2016).

Regarding the “NAO as a relational agent” category (Table 2), seven results have been included.
Manzi et al. (2020) investigated the attribution of mental states to two humanoid robots, NAO and Robovie, differing in degree of anthropomorphism. 5-, 7-, and 9-year-old children attributed mental states to the first robot because it exhibited human-like characteristics, while the second robot was perceived as having more mechanical features. The research group's findings demonstrate that 5-year-old children have a greater tendency to anthropomorphize robots compared to older children, regardless of the type of robot, thus supporting previous findings (Manzi et al., 2017; Di Dio et al., 2018; 2019; 2020a; 2020b). Additionally, while this result may seem counterintuitive to what was mentioned earlier, the authors observed a difference in emotional attribution toward NAO, noting that younger children attributed fewer negative emotions to the robot compared to older children (Manzi et al., 2020).
About the establishment of a children-robot relationship, and specifically considering dimensions of trust, closeness, cognitive and affective perspective-taking, and social presence, Van Straten et al. (2022) aimed to experimentally investigate self-disclosure and question-asking by a social robot toward children. The authors discovered that, for example, asking questions increased children’s trust in the robot and influenced their perception of the robot as being more capable of perspective-taking. Neither question-asking nor self-disclosure affected children's feelings of closeness toward the robot or their experience of its social presence. Furthermore, it was found that children's experience of the robot as an actor that they could befriend remained unaffected (Van Straten et al., 2022).
Van Straten et al. (2020) experimentally investigated the effects of transparency regarding a robot’s lack of human psychological capabilities (intelligence, self-awareness, emotions, identity construction, social cognition) on children's perceptions of the robot itself and their relationship with it. Transparency (i.e., providing children with detailed information on NAO’s lack of human qualities) negatively affected the child-robot relationship in terms of decreased trust but it did not influence feelings of closeness toward the robot. In the absence of transparent information, children tended to be ambivalent in perceiving the animated state of the robot. Conversely, ratings of social presence were particularly high in the transparency condition (Van Straten, 2020). According to the authors, this indicates that children's experience of social presence decreases but does not disappear when information about a robot's lack of human psychological capabilities is provided.
Stower et al. (2022) analyzed children’s social attitudes when interacting with NAO to complete a task in which they programmed Cozmo (a truck robot) to navigate on a physical map. There were two conditions: one in which NAO provided correct information, while the other in which the robot provided incorrect information. The authors’ findings demonstrate that a robot error had no significant effect on children’s social attitudes, behavior, or task performance. The authors suggested two possible explanations for this: the first possibility is that no child noticed the error due to the numerous elements within the research environment (NAO, Cozmo, the map and the tablet); the second possibility is that some children perceived the error but did not consider it relevant to the interaction and the task. In this case, children might have decided not to consider NAO’s mistake because the robot would have admitted its mistake, thus preserving children’s trust.
In several studies, NAO acts as a mediator between the child and the environment or more specifically another digital or robotic technological object. In the study by Flanagan et al. (2023), the central theme is perceived agency. The authors studied the beliefs of children aged 4 to 11 about two familiar technologies: Roomba and Amazon Alexa, compared to beliefs about a humanoid robot like NAO. Using feature clustering, they figured out that children’s beliefs about the characteristics of technological agents are organized into three distinct groups: having experiences, having minds, and ability to act in moral scenarios. They also found that older children tended to view the functionality of technologies as tightly bound by their programming. The results of the study show that young children don’t seem to lose sight of the fact that they are interacting with artifacts designed for a particular function. Also, with this awareness, younger children attribute action to technologies more than older children.
Okanda and Taniguchi (2022) investigated whether preschool-age children exhibit a tendency towards “yes” responses to yes-no questions asked by a humanoid robot. Their hypothesis was that the responses would be similar to those given in the presence of familiar humans, with younger children, specifically three-year-olds, showing a “yes” bias regardless of the conditions compared to older children. The hypothesis was only partially supported. Younger children did indeed exhibit a “yes” bias, as an automatic or impulsive response (Okanda & Itakura, 2010, 2011); however, the older children showed a “no” bias. According to the authors, these results can be explained by stating that the robot used in the study did not exert a high level of social pressure, and the older children did not feel obligated to respond obediently.

**Table 1** - NAO as an informational and educational tool" (n = 17 studies).

| *Authors (year)* | *Sample* | *Outcomes investigated* | *Main results* |
|---|---|---|---|
| Ahmad, M.I., Mubin, O., & Orlando, J. (2017) | 23 children aged 10-12 | NAO performed 1) game-based adaptations, 2) emotion-based adaptations, and 3) memory-based adaptation | Emotion-based adaptations of NAO were found to be the most effective, even more than memory-based adaptations. |
| Ahmad, M.I., Mubin, O., Shahid, S., & Orlando, J. (2019) | 24 children aged 10-12 | Emotion and memory model for a social robot | Interaction with NAO presenting positive emotional feedback facilitates vocabulary learning. |
| Alhashmi, M., Mubin, O., & Baroud, R. (2021) | 20 fourth grade students | NAO Co-teacher | NAO's role as co-teacher has been appreciated by students, while teachers express some concerns. |
| Almousa, O., & Alghowinem, S. (2023) | 5 preschool children aged 3-5; 2 preschool teachers | Personalized learning | The personalized interaction with NAO showed a positive potential in increasing the children's learning. |
| Basori, A.H. (2020) | Children, number and age unknown | Body touch and character recognition | The robot was able to achieve a high 75% recognition rate for kid's manuscripts. |
| Bono, A., Augello, A., Pilato, G., Vella, F., & Gaglio, S.(2020) | 1 child aged unknown | Interactive storytelling | NAO's role as a storyteller increases credibility if it communicates the internal states of the characters. |
| Crompton, H., Gregory, K., & Burke, D. (2018) | 3 teaching assistants and 50 children aged 3-5 | Student development in all learning domains | Interaction with NAO has made a greater respect for turns in cooperation. |
| Cuadrado, L.-E.I., Riesco, Á.M., & De La Paz López, F. (2016) | 20 children aged 10-11 (scratch use experience) 2 children aged 8 and 11 (interaction with NAO) | Personalized emotional pedagogical support | Interacting with NAO must be dynamic enough not to frustrate or bore. |
| De Souza Jeronimo, B., de Albuquerque Wheler, A.P., de Oliveira, J.P.G., Melo, R., Bastos-Filho, C.J.A., & Kelner, J. (2022) | 20 children aged 9-11 | Musical education | NAO emotional expressivity does not offer room for improvement, while Zenbo offers alternative skins for facial expressions. |
| Levinson, L., Gvirsman, O., Gorodesky, I.M., Perez, A., Gonen, E., & Gordon G. (2021) | 46 children aged 6.7 ± 0.9 | STEM teaching | Interaction with NAO at a summer camp is effective but needs to be made more dynamic. |
| Lopez-Caudana, E., Ponce, P., Mazon, N., & Baltazar, G. (2022) | 26 third grade students and 25 fourth grade students | Physical education | Interaction with NAO improves children's attention span and motivation. |
| Molenaar, B., Fernández, B.S., Polimeno, A., Barakova, E., & Chen, A. (2021) | 32 children aged 8-11 | Robot-assisted language learning | Tone of voice convergence between NAO and student has no significant effect on language learning. |
| Neumann, M.M., Neumann, D.L., & Koch, L.-C. (2023) | 40 preschoolers aged 4.58 | Drawing activity | In the drawing activity together with NAO, 83% of the children followed the instructions and 60% interacted verbally. |

| *Authors (year)* | *Sample* | *Outcomes investigated* | *Main results* |
|---|---|---|---|
| Peretti, G., Manzi, F., Di Dio, C., Cangelosi, A., Harris, P.L., Massaro, D., & Marchetti A. (2023) | 112 children aged 5-6 | Recognize, and morally evaluate, lies and mistakes produced by a human as compared to a NAO robot | When children interact with NAO they understand mistakes better than lies. |
| Ponce, P., López-Orozco, C.F., Reyes, G.E.B., Lopez-Caudana, E., Parra, N.M., & Molina, A. (2022) | 186 4th, 5th, and 6th grades of elementary schools | STEM Teaching and physical education | Students prefer a robotic teaching environment to reinforce theoretical concepts seen in the classroom. |
| Rosi, A., Dall'Asta, M., Brighenti, F., Del Rio, D., Volta, E., Baroni, I., Nalin, M., Coti Zelati, M., Sanna, A., Scazzina, F. (2016) | 112 fourth grade students | Nutritional aspects | Game-based educational interaction with NAO increased children's nutritional knowledge. |
| So, S., & Lee, N. (2023) | 20 children aged 9-12; 15 guardians aged 26-46 | Teach a mathematical concept of measurement | Children's impressions of NAO focused on involvement and curiosity. |

**Table 2** - NAO as a relational agent (n= 7 studies).

| *Authors (year)* | *Sample* | *Outcomes investigated* | *Main results* |
|---|---|---|---|
| Flanagan, T., Wong, G., & Kushnir, T. (2023) | 127 children aged 4-11 | Beliefs about familiar technologies and NAO | Young children attribute agency to technologies more than older children. |
| Ioannou, A., Andreou, E., & Christofi, M. (2015) | 4 preschoolers aged 3-5 | Thoughtful and caring attitudes | Preschoolers demonstrate caring behaviors such as hug to NAO. |
| Manzi, F., Peretti, G., Di Dio, C., Cangelosi, A., Itakura, S., Kanda, T., Ishiguro, H., Massaro, D., & Marchetti A. (2020) | 189 children aged 5-9 | Anthropomorphism | Children tend to anthropomorphize humanoid robots that also have some mechanical characteristics. |
| Okanda, M., & Taniguchi, K. (2022) | 45 children aged 3-5 | Yes-no answers to questions about familiar and unfamiliar objects | The 3-years-old children, unlike older preschoolers, showed yes bias with NAO. |
| Stower, R., Abdelghani, R., Tschopp, M., Evangelista, K., Chetouani, M., & Kappas, A. (2022) | 72 children aged 7-10 | Perceived agency | The authors found no quantitative effects robot error on children's self-reported attitudes, behavior, or task performance. Age was also not significantly correlated. |
| Van Straten, C.L., Peter, J., Kühne, R., & Barco, A. (2020) | 144 children aged 8-9 | Transparency about robots' machine nature | Transparency reduced children's perception of the robot in terms of animation, anthropomorphism, social presence, and perceived similarity. |
| Van Straten, C.L., Peter, J., Kühne, R., & Barco, A. (2022) | 293 children aged 7-10 | Self-disclosure | Children's consideration of the robot as social actor and a potential friend did not differ across conditions. |

Furthermore, four-year-old children, who are known to say “no” to adults (Okanda et al., 2012), did not do so with NAO. It seems that four-year-old children may perceive NAO as an artifact that falls somewhere between an unknown-authoritative figure and a familiar-friendly one.
The study by Ioannou et al. (2015) showed that children aged 3-5 tend to interact with NAO as if it were one of them. Furthermore, the study demonstrated that children pay particular attention to NAO when it needs help (e.g., when it falls), displaying caring and friendly behaviors. This finding is consistent with the research by Tanaka, Cicourel, and Movellan (2007), who argued that children between 8 and 24 months old exhibit a variety of social behaviors around a robot, including treating it as a peer. This finding suggests that humanoid robots evoke feelings and may facilitate the acquisition and awareness of the importance of care behaviors.

## 4. Discussion and Conclusions

The aim of this systematic review was to identify the characteristics of the interaction between the social robot NAO and children in educational and relational contexts. From an initial total of 116 studies, we obtained a total of 24 studies through two rounds of exclusion. For the sake of clarity, we divided the results into two main categories: 1) “NAO as an informational and educational tool”, and 2) “NAO as a relational agent”. This division allowed us to capture the structural and operational characteristics that these studies share more effectively.
Regarding studies in the field of education and learning, the authors agree on the identification of the main emotions that influence children’s immediate perception of robots, such as recognizing them as friendly, fun, curious, and positive (Ponce et al., 2022; So & Lee, 2023). Positive emotional feedback is specifically highlighted for enhanced lexical learning, fostering children’s appreciation of NAO as a co-teacher. Additionally, programming NAO to respect turn-taking in question-answer dynamics and cooperative activities is found to be significant, promoting dynamic responses, actions, and gestures that facilitate learning and cultivate curiosity. It is essential to continue studying this phenomenon to improve our understanding of children’s actual learning, especially on the long-term (Baddeley, 2007; Sherwood, 2015). This result can only be achieved through longitudinal studies.
In studies within the realm of relationship, it is noteworthy that research by various authors aligns with the understanding that children, particularly those under the age of 6, tend to attribute consciousness to objects, a phenomenon known as animism (Di Dio et al., 2020b). This tendency tends to diminish significantly around the age of 9.
Anthropomorphization is a noteworthy phenomenon to be taken into account during the robot programming phase, due to its potential influence on the structural aspect of the robot as well as paraverbal and tone of voice aspects.
It is also important to acknowledge that, despite the anthropomorphization tendency, children can generally distinguish between a human being and a robot, especially based on the attribution of human psychological states, such as intelligence, self-awareness, emotionality, identity construction, and social cognition. The exploration of transparency (i.e., directly informing children that robots do not experience those psychological states) and its impact on children's perception during interactions with social robots contributes to a nuanced understanding of mental state attribution (AMS) and the formation of relationships with humanoid robots.
Moreover, this line of research sheds light on children's expectations, perceptions of robotic design, and imaginative features influencing the development of the animism phenomenon. The theoretical insights gained from these studies may offer valuable guidance for the future development of humanoid robots, aiming to promote richer and more respectful coexistence and conviviality.
Overall, the research analyzed in the present review highlights key practical aspects for the utilization of social robots, particularly NAO, in educational and relational contexts with children. Practical considerations encompass the recognition of positive emotional feedback to facilitate lexical learning and the endorsement of NAO as a co-teacher. The programming of NAO to adhere to turn-taking in interactions is also emphasized. Furthermore, attention is directed towards anthropomorphization during NAO programming, emphasizing the influence of structural, paraverbal, and tonal aspects. Transparency emerges as a pivotal element shaping interactions, diminishing children's perception and altering the spontaneous nature of engagements. Lastly, some studies propose that theoretical and practical insights provided by the research can guide the future development of social robots, aiming to foster a more enriched and respectful coexistence.
In conclusion, this review aimed at capturing both the potential uses of social robots in the fields of education and relationship-learning, as well as key aspects to keep in mind when programming NAO for such purposes. Among these, we highlight the positive effects of personalized learning, closely linked to the ability of robots to assume various social roles; the playful experience that these technologies can provide during the transmission of educational content, which can be connected to studies on transparency and

control, where relevant issues regarding the operation of biases in interaction with social robots have emerged. Another important research direction for both fields is related to aspects of mutual care: from the child to the robot and vice versa. This latter line of research raises new ethical and developmental psychology questions. Lastly, we emphasize the significance of studies on anthropomorphism, which raise new research questions concerning design and, therefore, the perception of differences and similarities between humans and robots in terms of action and aesthetics.

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