Enhancing Learning and Therapy for Children with Autism: Innovative Activities with the NAO Robot

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***Abstract*— Worldwide, autism affects 1 in 100 children, with diagnoses steadily rising since the 2000s. Romania lacks official statistics on autism prevalence, but global estimates suggest similarity. Children with autism struggle with social interactions and verbal communication, prompting interest in social robots for therapy and education. Tailored robot-assisted sessions offer potential for cognitive development, vocabulary enhancement, social interaction, and behavioral stimulation like concentration and attention. The NAO robot's user-friendly design, technical capabilities, and integrated features make it well-suited for these purposes. This paper presents activities that exemplify the concept of "learning through play," allowing children to engage in exploration, experimentation, and effective learning in an enjoyable manner.**

Keywords—NAO robot; autism; learning activities; therapy;

I. Introduction

Autism is a neurological disorder that affects a person's behavior, communication, and interaction with others. It is termed a "spectrum disorder" because symptoms and severity vary from one individual to another. Diagnosis is typically made by a doctor based on observation of the child's behavior, categorizing it as a behavioral disorder rather than a disease, as it cannot be identified through standard medical tests. According to the World Health Organization (WHO), approximately 1 in 160 children is diagnosed with autism spectrum disorder (ASD). However, other studies suggest that the actual rate may be higher, with estimates indicating a ratio of 1 in 59 children in certain regions of the world. This increase in prevalence can be attributed in part to improved awareness and diagnosis, as well as expanded diagnostic criteria. It is important to note significant variations in autism diagnosis and reporting between countries and regions, reflecting differences in access to healthcare services and diagnostic capacity.

A. Social robots

Social robots are designed to interact and collaborate with humans in a natural and beneficial manner. They are being adapted and used in various fields such as healthcare, education and assistive living. In the following, we will briefly introduce some social robots and their characteristics.

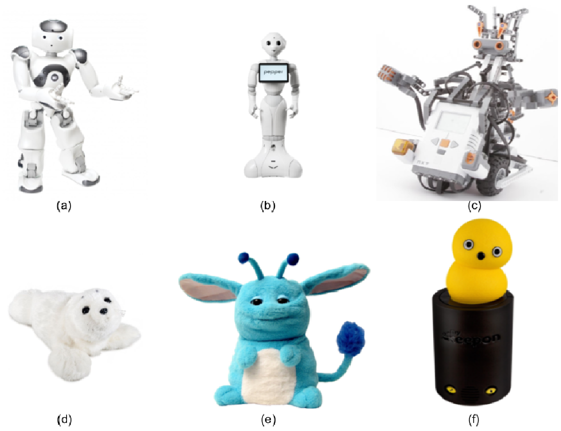

Fig. 1. Examples of social robots: (a) NAO, (b) Pepper, (c) Phobot, (d) Paro, (e) Popchilla and (f) Keepon Pro

Developed by the French robotics company Aldebaran in 2008 and acquired by the Japanese company Softbank Robotics in 2015, NAO (Fig. 1(a)) serves as a valuable aid in research, education, and therapy. Known for its friendly appearance, technical capabilities, and ability to interact with humans, NAO is among the most popular humanoid robots worldwide. It can be controlled using a dedicated application, Choregraphe, and programmed in various languages such as Python, C++, and Java. Pepper (Fig. 1(b)), also developed by the aforementioned French company in 2014 is renowned for its ability to interact naturally and empathetically with people. The robot has a friendly design, stands about 120 cm tall, and features a touchscreen on its chest. It is equipped with cameras, microphones, and sensors for facial and voice recognition.

Created by students from the University of Amsterdam, Phobot (Fig. 1(c)) is designed for children with anxiety and phobias. It is built from LEGO Mindstorms NXT pieces and a series of RFID sensors. When Phobot detects a larger and more intimidating robot, it retreats and circles around, mimicking a person in a state of panic. Paro ((Fig. 1(d)), is designed to provide animal-assisted therapy for hospital patients. Shaped like a baby seal, it has soft, white fur, is small in size, and easy to hold, which gives it a friendly and soothing appearance. Paro is equipped with five types of sensors: light, temperature, posture, touch, and sound, that allow it to perceive people and its surroundings. Developed by Interbots in Pittsburgh, Popchilla initially started as a toy but proved to be a valuable tool for therapists working with children with autism. It has a

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friendly appearance, with expressive eyes and a colorful body. Equipped with sensors and cameras, Popchilla ((Fig. 1(e)) responds to voice commands, facial expressions, and gestures, providing a natural interaction experience. Keepon ((Fig. 1(f)) is used to monitor and enhance social interaction, particularly for children with autism, helping them improve their social skills and reduce anxiety. The robot has a soft, yellow body, with two eyes and a small nose, making it non-intimidating for children.

B. Literature review

The NAO robot has been widely employed by researchers in experimental therapy sessions for children with autism spectrum disorder. Using the robot, they have successfully addressed objectives such as enhancing emotional comprehension, fostering vocabulary development, and refining behavioral and cognitive skills. In the following we will review a few projects that involved NAO for learning purposes.

In the HERO project [1], 18 therapy protocols were implemented using the NAO robot. These activities were specific to Applied Behavior Analysis (ABA) and Early Start Denver Model (ESDM) therapies. The project's goal was to enhance the social, adaptability, and verbal capabilities of autistic children. Another therapeutic program, Rob'Autisme [1], proposed using NAO as a storyteller. This therapy consisted of 20 hours per week, divided into 10 hours for programming the robot to move and speak, and 10 hours for preparing the performance. At the end of the study, researchers concluded that while the robot cannot replace a therapist, it serves as a catalyst, enabling cognitive connections.

The project NAOtismIA [1], classifies the activities implemented in three levels of difficulty, starting from simpler words (e.g., red), to more complex tasks (e.g., "show red" or "show me the red color"). With the help of the NAO robot, three applications were developed: "Dire bonjour," in which NAO answers the teacher's questions about the date; individual sessions to improve vocabulary through the recognition of objects and colors; and activities to develop motor skills through a yoga application. The DREAM [1],[2],[3] was conducted from 2014 to 2019 and aimed to improve social skills like imitation and joint attention in autistic children. Activities were designed as games with the NAO robot giving instructions and feedback, while therapists supervised. Involving 69 children from Romanian autism treatment centers, the project included 12 sessions: initial and final assessments, and interventions where children interacted with either a human or the robot. Results indicated that interactions with the robot were more beneficial, with parents noting improvements in their children's social skills.

The study described in [4], aimed to see if stories told by a humanoid robot-like NAO could help children with autism better understand emotions and improve their social interactions. Conducted over two years with children aged 4 to 14, the experiment found that the robot's neutral appearance, monotone voice, and predictable movements made it easier for children to interact with it. As a result, they understood the stories better and became more empathetic and engaged with others compared to a group where a psychologist was the storyteller, which did not show significant results. The authors of [5], proposed a method to recognize facial expressions and emotion to facilitate natural communication between humans and NAO. To recognize emotions, the method used a neural network which achieved an accuracy of around 90% for *happy* and *sad*, 75% for *surprised* and *scared* and lower accuracy for *angry* and *neutral* expressions. In [6], researchers explored the use of the NAO robot in speech and educational therapy sessions for children with diverse needs. The study highlighted the necessity for specialized software to cater to each child's unique requirements and behaviors. A game using the NAO robot as a conversational agent to enhance environmental awareness, is described in [7]. Participants interacted with the robot, which recognized their emotional states and responded accordingly. Results were promising, with only 5 incorrect responses out of 25. Emotions such as anger, surprise and disgust were identified with lower accuracy, while the others were effectively recognized. In [8], researchers examined how children, both with and without hearing impairments, perceived emotions conveyed by the NAO robot through visual cues alone. Participants watched videos of the robot's reactions and identified its emotions. Results showed that both groups successfully recognized the robot's emotional expressions, suggesting potential applications for further research in this area.

In this paper, we present a series of activities that can be included in therapy/learning sessions with the humanoid NAO robot. The activities are designed to illustrate the concept of "learning through play," allowing children to explore, experiment, and acquire knowledge and skills in an enjoyable and effective manner.

II. Human-Robot Interaction for Therapy and Learning

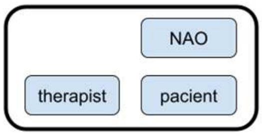

Fig. 2. The placement of principal actors in the therapy room

In a therapy session, the participants, as illustrated in Fig. 2, are the therapist, the NAO robot, and the patient. We imagined the following arrangement positions: the child directly in front of the robot to ensure focused interaction, while the therapist sits to the child's left or right. This strategic setup minimizes distractions and pressure on the child, promoting a relaxed and secure environment. The NAO robot's central placement is crucial, as its responses are designed to capture and maintain the child's attention, facilitating active engagement. The therapist's role, positioned for discreet support, allows for careful observation and timely intervention without interrupting the child's concentration on the robot. This arrangement optimizes the therapeutic process by fostering clear interaction and effective support, contributing to the child's progress.

The architecture of the developed solution for robot-assisted therapy is illustrated in Fig. 3 and is based on two main components: the activities implemented with the NAO robot and a dedicated application for the therapists, from which they can control and monitor the activities. The first component focuses on direct interactions between the child and the robot, using programmed dialogues to stimulate the child's social and cognitive skills. The second component is the therapist's application, an essential tool that allows therapeutic staff to select and adjust activities, track patient progress, and provide interventions when necessary. This dual architecture ensures personalized, adaptable, and effective therapy, combining the advanced technology of the robot with the therapist's expertise and clinical judgment.

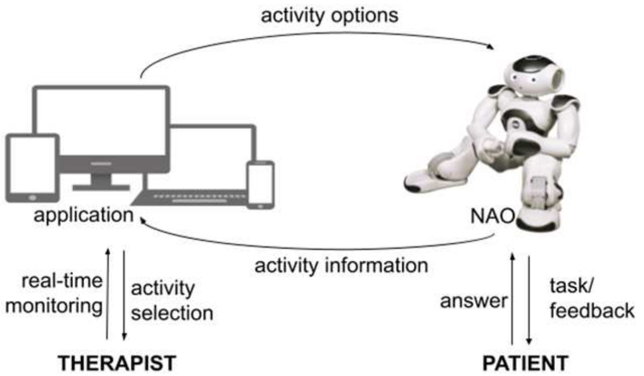

Fig. 3. Solution pipeline

A. NAO-based activities

TABLE I. IMPLEMENTED ACTIVITIES

Level	Dificulty	Activity
Level 1	easy (word)	First Meeting with the Robot
		Numbers – learning (image-based)
		Geometric Shapes – learning (image-based)
		Animals – recognition (image-based)
		Colors – recognition (image-based)
Level 2	medium (action & word)	Animals – recognition (image-based)
		Colors – recognition (image-based)
		Fruits – recognition (image-based)
Level 3	hard (phrase)	Animals – recognition (description-based)
		Musical Instruments – recognition (audio)
		Colors – recognition (image-based)
		Animals – recognition (image-based)

To facilitate a gradual developmental progression, the activities are organized into three levels of difficulty, inspired by the NAOtismIA project [1]. This structure allows children to advance incrementally, starting with simple tasks and moving towards more complex ones. Each activity begins with a brief description, followed by the specific requirements for each level of difficulty. At **Level 1**, the tasks are simple and are formulated as a single word. For instance, in the *color recognition* activity, the robot will simply state the color (e.g., **red**). This level focuses on familiarizing the child with basic concepts and recognizing individual terms. At **Level 2**, the tasks become more complex, incorporating a verb and providing clear direction (e.g., **show red**). This level introduces actions and teaches children to associate words with actions, thereby facilitating a deeper understanding of language and context. At **Level 3**, the tasks are formulated in complete sentences: (e.g., Show me the red color). This advanced level helps children comprehend and respond to more complex commands, developing their ability to interpret and react to full sentences. This progressive approach ensures a holistic development of the child's linguistic and cognitive abilities, providing an opportunity to learn through play in a structured and effective manner.

Considering that a therapy session for a child with autism typically lasts between 30 to 50 minutes, depending on the type of therapy, we aimed to design activities that are brief enough to prevent the child from feeling overwhelmed and losing concentration. Based on the child's communication style, behavior, and the severity of the diagnosis, the therapist will select the appropriate difficulty level and determine the frequency of each activity.

Some of the implemented activities, particularly those that are image-based, require the use of flashcards displaying various items, Fig. 4. These flashcards serve as visual aids to facilitate the learning and interaction process. Additionally, certain activities come with detailed descriptions to guide the user through the task, ensuring clarity and understanding. For other activities, audio cues are provided, allowing participants to engage with the content through auditory instructions. This multimodal approach ensures that the activities cater to diverse learning preferences and needs, enhancing the overall effectiveness of the therapy sessions.

Fig. 4. Examples of flashcards used for the *animals – recognition* (top) and *colors – recognition* (bottom) activities

In the audio-based activity (i.e., *musical instruments - recognition*), the NAO robot plays sounds from three different instruments for the child, each lasting a few seconds. The child must listen carefully and identify the instruments based solely on the sounds, such as a piano, trumpet, or violin. This activity aims to enhance the child's ability to recognize sounds, develop auditory and memory skills, and stimulate concentration and attention to detail. It also fosters prompt and accurate responses to the robot's questions, contributing to the overall development of listening and communication skills.

In activities that use images, 4, 5, or 10 flashcards, each depicting a different concept such as an animal, a color, or a number, will be placed in front of the child. During the recognition activities, the NAO robot will ask the child to show a specific flashcard. The child must identify and show the corresponding card to the robot. This activity is designed to help the child improve their knowledge of colors and animals, learning to recognize and correctly name them. Additionally, the activity aids in developing the ability to follow instructions, concentration, and attention, while also stimulating visual memory and association skills.

In the learning activities, the child actively selects and presents cards to the NAO robot, which then identifies and names the concept illustrated, whether it's a number or a geometric shape. This interactive process not only encourages the child's engagement and participation but also reinforces their ability to associate visual cues with corresponding concepts. Through these activities, the child enhances their understanding and recognition of numbers and animals, while simultaneously developing important cognitive and communicative skills. This approach not only fosters learning through hands-on interaction but also promotes a stimulating and engaging educational environment. Each question is asked up to three times; if the child does not answer correctly after the third question, the activity transitions to the subsequent task. Additionally, the therapist retains the authority to pause the activity if it is deemed too complex for the child.

The robot operates without any predefined functions or software. Thus, all activities must be designed and implemented from scratch. The robot does not support the Romanian language; therefore, it communicates in English.

B. *Application*

To assist the therapist in conducting therapy sessions more efficiently, we have developed an interface in addition to the implemented activities. Through this interface, the therapist can log into their account, add or view the patients visiting the clinic and the activities they have participated in so far, connect to the NAO robot, and select appropriate activities based on the patient's level. All this information is ultimately saved in a database for more effective monitoring.

III. EXPERIMENTAL RESULTS

The conducted experiments focused exclusively on evaluating the application and the activities implemented using the NAO robot. The primary objectives were to assess technical functionality, user interface, and the efficiency of interactions between the robot and users. Given that user testing with real patients requires ethical committee approval, our evaluations were confined to usability aspects within a controlled laboratory environment. This approach ensures that all system components operate as expected before advancing to other testing scenarios.

Fig. 5. Testing the *animals – recognition* activity in a laboratory setup

During the laboratory tests, we observed three distinct scenarios with users interacting with the robot. In the first scenario (S1), users were encountering the robot for the first time, navigating initial interactions with curiosity and uncertainty. The second scenario (S2) involved users who were somewhat acquainted with the robot, displaying a moderate level of comfort and familiarity in their interactions. In the third scenario (S3), users demonstrated ease and confidence in their interactions with the robot, indicating a high level of comfort and proficiency.

In each of the aforementioned scenarios, we measured the time required for completing the activities with the robot. These timings and are presented in detail in TABLE II. This quantitative analysis provides valuable insights into how user familiarity and comfort levels influence task completion efficiency. By systematically documenting these findings, we aim to underscore the impact of user experience on interaction dynamics and operational effectiveness within therapeutic and educational contexts involving humanoid robots like NAO.

TABLE II. TIME COMPLETION (MINUTES) OF THE DESIGNED ACTIVITIES

Activity	**S1**	**S2**	**S3**
Musical Instruments – recognition (audio)	4-5	3-4	2-3
Animals – recognition (description-based)	3-4	2-3	1-2
Colors – recognition (image-based)	4-5	3-4	2-3
Animals – recognition (image-based)	4-5	3-4	2-3

In conclusion, our laboratory tests identified distinct user interaction scenarios with the NAO robot. Completion times for **Level 3** activities varied: 3-5 minutes for first-time encounters (S1), 2-4 minutes for somewhat acquainted users (S2), and 1-3 minutes for highly proficient users (S3), as shown in TABLE II. These findings underscore how user familiarity significantly impacts task efficiency.

IV. CONCLUSIONS

The capabilities and ability of social robots to interact naturally with people in diverse settings such as homes, schools, and hospitals, represent a significant aid in enhancing social and cognitive skills and fostering beneficial behaviors.

In this paper, we presented some activities designed to support therapists in the therapy and education of children on the autism spectrum. The activities were implemented with the NAO robot and were structured into three levels of difficulty. To maintain children's attention and prevent exhaustion, the activities require a short completion time. Also, they are implemented in a flexible manner, allowing for duration adjustments based on individual needs and responses.

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