

ALAN: An Adaptive Social Robot for Teaching Emotional Skills to Children with Autism Spectrum Disorder

Cássio W. M. Diniz¹, Sara L. Melo¹, Claudiney R. Tinoco¹

¹Department of Computing (FACOM), Federal University of Uberlândia (UFU)
2121, João Naves de Ávila Ave., 38.408-100, Uberlândia, MG, Brazil

{cassio.diniz, sara.melo, claudiney.tinoco}@ufu.br

Abstract. *Autism Spectrum Disorder (ASD) is a neurodevelopmental condition that affects skills related to communication, social interaction, and behaviour from early childhood, with a significant increase in diagnoses observed over the last decade. In this context, early intervention plays a fundamental role in the development of the affected abilities. Several therapeutic approaches have been employed to stimulate cognitive, social, and emotional skills in children with ASD. Among these approaches, robotics has shown promising results in supporting therapies aimed at autistic children. However, challenges still remain regarding the ability of robots to express emotions naturally, stimulate social interactions such as eye contact and physical interaction, and adapt teaching strategies to the specific needs of each child. Therefore, this work proposes a robotic platform for teaching emotional skills to children diagnosed with ASD. The robot has an appearance designed to be friendly, being capable of expressing emotions and sounds, as well as conducting educational activities and games focused on emotional recognition and learning. In addition, the platform collects data during interactions, enabling the adaptation of the teaching process according to the progress and difficulties observed in each individual. Thus, the proposed platform seeks to contribute to the development of emotional skills in children with ASD by providing a therapeutic environment that can be perceived as more welcoming, interactive, and personalized.*

Keywords: *Socially Assistive Robotics. Autism Spectrum Disorder. Emotional Skills. Affective Computing. Educational Games. Adaptive Models.*

1. Introduction

Autism Spectrum Disorder (ASD) is one of the most prevalent neurodevelopmental disorders worldwide and is characterized by differences in communication, social interaction, and behavioural patterns [Zeidan et al. 2022]. Current epidemiological studies indicate a continuous increase in the global prevalence of ASD [Okoye et al. 2023]. In Brazil, approximately two million individuals have ASD [Sukiennik et al. 2022]. Given that developmental outcomes are strongly influenced by intervention timing, early and targeted developmental interventions throughout childhood have received considerable attention in recent years [Augusto et al. 2025].

Among the developmental domains affected by ASD, emotional development plays an important role because it directly influences communication, social interaction, and interpersonal relationships [Restoy et al. 2024]. Children with ASD often experience difficulty recognizing emotions from facial expressions and interpreting the emotional

states of others [Yeung 2022]. This challenge is not necessarily related to intellectual ability, as many children can identify individual facial features but may struggle to infer the emotional meaning conveyed by their combination.

To address these difficulties, several educational and therapeutic approaches have been proposed to support the development of emotional skills in individuals with ASD [Qin et al. 2024]. These interventions employ structured activities and methodologies to improve emotion recognition, interpretation, and expression, helping children develop skills that are fundamental for communication and social interaction [Mittal et al. 2024, Hryntsiv et al. 2025]. Consequently, a variety of tools have been developed to support the teaching of emotions in a structured and engaging manner.

Recent advances in assistive technologies have further expanded the range of tools available for emotion-focused interventions [Syriopoulou-Delli and Gkiolnta 2022]. These technologies include interactive systems that provide adaptive feedback, multimodal interaction, and personalized learning experiences, making emotion-focused interventions more engaging, accessible, and effective [Wohofsky et al. 2022]. Together, these advances have paved the way for intelligent interactive systems capable of delivering more personalized educational interventions for children with ASD.

In this context, socially assistive robots have emerged as promising tools for supporting educational and therapeutic interventions. These robots are capable of attracting and sustaining children's attention while delivering adaptive, interactive, and personalized learning experiences, which has attracted considerable research interest [Saleh et al. 2021]. Several robotic platforms have been proposed for interventions involving children with ASD [Islam et al. 2023], with studies reporting improvements in emotion recognition, social participation, and communication skills.

Despite the promising results reported in the literature, existing robotic platforms for children with ASD present important limitations regarding the integration of educational resources, personalized interaction, emotional learning, and continuous assessment of learning progress within a single platform. In addition, several approaches rely primarily on isolated activities rather than combining facial expressions, visual cues, and interactive educational activities into a unified adaptive learning environment [Islam et al. 2023]. These limitations highlight the need for more comprehensive robotic platforms capable of supporting personalized emotion-focused interventions.

Based on these observations, this work presents ALAN, an adaptive socially assistive robot specifically designed for teaching emotional skills to children with autism spectrum disorder. ALAN combines animated facial expressions, audio feedback, colour-based emotional cues, and educational games to support the development of emotional skills through personalized and adaptive child-robot interactions.

This work is organized as follows. Section 2 reviews related works on socially assistive robots for children with ASD. Section 3 presents ALAN, describing its robotic platform, operational workflow, and adaptive educational framework. Section 4 discusses the main characteristics and limitations of the proposed platform through a qualitative assessment. Finally, Section 5 concludes the paper and outlines future works.

2. Related Works

The use of robotics for teaching emotions to children with ASD has been explored as a promising approach to improve their ability to recognize and express emotions. According to [Ismail et al. 2018], robots can provide structured and predictable learning environments, making them particularly suitable for therapeutic interventions involving children with ASD. Expanding on this perspective, [Saleh et al. 2021] reported that social robots offer several advantages over conventional technological tools for teaching social and emotional skills. More recently, [Islam et al. 2023] highlighted the effectiveness and safety of robot-assisted interventions for promoting social and emotional development. This growing interest has led to the development of several robotic platforms specifically designed to support children with ASD.

One of the most established robotic platforms used in interventions for children with ASD is **Kaspar**, developed by the University of Hertfordshire [Wood et al. 2021]. Designed with the appearance of a young child, the robot can respond to tactile stimuli and perform activities focused on body awareness, imitation, social interaction, and cognitive development. Its use in guided games and social activities has demonstrated the potential of socially assistive robots to promote engagement and support learning processes.

Following a similar approach, **NAO** has been widely employed in educational and therapeutic contexts involving children with ASD [Gouaillier et al. 2009]. This humanoid robot can walk, speak, dance, and perform programmable activities, enabling structured interaction scenarios. Through these activities, NAO has been used to stimulate communication, imitation, and social participation.

Beyond supporting social interaction, researchers have also explored robotic platforms designed to support cognitive and motor development. An example is **Maria T21**, developed at the Federal University of Espírito Santo [Panceri et al. 2021]. The robot integrates educational games with sensors and cameras capable of monitoring children's behaviour during activities. This combination allows both the execution of intervention tasks and the collection of information that can support therapeutic assessment.

Another important direction has been personalized interventions. In this context, **KIWI** was proposed as a socially assistive robot capable of adapting educational activities according to the child's performance [Jain et al. 2020]. The platform combines educational games, speech interaction, animated facial expressions, and monitoring systems to maintain engagement while supporting cognitive and social development.

The importance of personalization has also motivated the development of conversational robots such as **RABI** [So 2020]. Unlike platforms centred on physical interaction, RABI focuses primarily on verbal communication, encouraging social interaction through dialogues and motivational conversations. Its objective is to help children practice communication skills and appropriate social behaviours in different situations.

Regarding emotional skills, **FLASH** is an example of a robot developed for teaching emotions through facial expression modelling [Kedzierski and Janiak 2012]. Using a mechanical face capable of reproducing basic emotional expressions, the platform encourages users to associate facial configurations with emotional states, contributing to the development of emotional recognition abilities.

A broader approach can be observed in **Moxie**, a companion robot designed to combine educational, social, and emotional interactions [Hurst et al. 2020]. Through speech, animated facial expressions, body movements, and monitoring sensors, the platform creates personalized experiences that seek to maintain engagement while supporting learning and emotional development.

Similarly, **Zeno** was designed to promote social, emotional, communicative, and behavioural skills through expressive and interactive interactions [Hanson et al. 2009]. Its ability to speak, gesture, and display facial expressions enables the execution of activities focused on emotional recognition and social engagement, making it suitable for interventions involving children with ASD.

Among the platforms specifically designed for autism interventions, **QTrobot** has received considerable attention [Ziafati and Nazarikhorrām 2017]. The robot combines speech, gestures, animated facial expressions, storytelling, and educational games within a single platform. Additionally, adaptive teaching strategies adjust activities according to the child's progress, providing a more individualized learning experience.

Pepper has also been successfully employed in educational and therapeutic settings [SoftBank and Aldebaran 2014]. This humanoid robot can recognize emotions, engage in verbal communication, and participate in interactive activities. Through storytelling, guided conversations, and collaborative tasks, Pepper has been used to encourage communication, social interaction, and emotional engagement.

The reviewed studies demonstrate that socially assistive robots can effectively support cognitive, social, communicative, and emotional development in children with ASD. Table 1 summarizes the main characteristics of the robotic platforms discussed in this review, highlighting the features most commonly adopted by existing systems. Most platforms combine social interaction, emotional support, and educational activities, whereas adaptive learning mechanisms are incorporated in only a limited number of systems. Motivated by these observations, ALAN was designed to integrate social interaction, emotional expression, educational activities, adaptive learning, and an expressive animated face within a single platform for teaching emotional skills.

Table 1: Main characteristics of the robotic platforms described for ASD interventions.

Robot	Social	Emotional	Educational	Adaptive	Expressive Face
Kaspar	✓	✓	✓	—	✓
NAO	✓	—	✓	—	—
Maria T21	✓	✓	✓	—	—
KIWI	✓	✓	✓	✓	✓
RABI	✓	—	—	—	—
FLASH	—	✓	—	—	✓
Moxie	✓	✓	✓	✓	✓
Zeno	✓	✓	✓	—	✓
QTrobot	✓	✓	✓	✓	✓
Pepper	✓	✓	✓	—	—
ALAN	✓	✓	✓	✓	✓

3. Proposition

This section presents ALAN, a socially assistive robot developed to support the teaching of emotional skills to children with ASD. The platform was designed based on characteristics identified in the literature as relevant for therapeutic interventions, including emotional expressiveness, educational interaction, and user engagement. To address these requirements, the robot combines facial emotion representation, audio feedback, and adaptive educational activities within a single platform.

3.1. Robotic Platform Design

The robot ALAN, shown in Figure 1, was designed according to the principles of the Lorenzian Kindchenschema theory [Borgi and Cirulli 2013], which emphasizes childlike proportions such as a larger head relative to the body and rounded features. These characteristics were adopted to create a friendly and approachable appearance to encourage interaction with children. To support both mobility and educational activities, the platform incorporates tracked wheels and two displays. The display located on the head is responsible for presenting facial expressions, while the display positioned on the torso provides access to educational activities and interaction feedback.

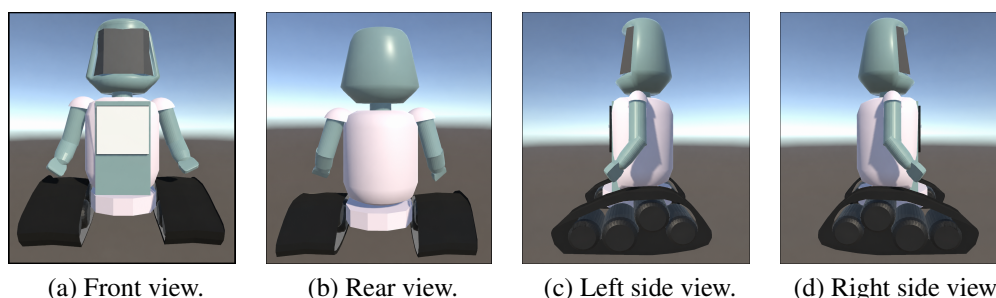


Figure 1: Overall view of the proposed 3D robot model.

To support the teaching of emotional skills, the robot was equipped with facial models representing the six basic emotions (happiness, sadness, fear, surprise, disgust, and anger) as well as a neutral expression¹, as illustrated in Figure 2. The proposed design focuses on the facial regions most commonly associated with emotional communication, namely the eyes, eyebrows, and mouth. By combining different configurations of these elements, the robot can visually represent distinct emotional states and use them throughout the educational activities.

The neutral expression was designed to convey attentiveness and serve as the default state of the robot during user interactions. The remaining facial models were created according to characteristic facial patterns associated with each emotion. Happiness is represented through a broad smile and relaxed facial features, whereas sadness employs lowered eyes and lowered facial expressions. Fear and surprise share features such as widened eyes and an open mouth, while disgust and anger are characterized by more pronounced facial configurations that emphasize aversion and tension. Together, these models provide a coherent visual repertoire capable of representing the six emotions addressed during the proposed learning activities.

¹ Animation frames illustrating the facial expressions are provided in Supplementary Material 1.

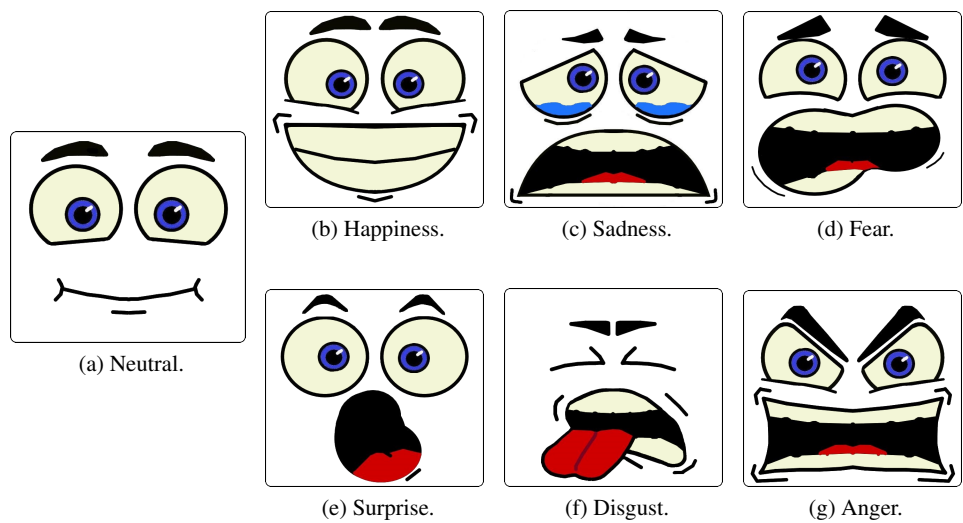


Figure 2: Proposed facial expressions designs for the robot.

These facial expressions were based on the emotional characteristics described by [Ekman et al. 1969, Ekman and Friesen 1978]. Rather than reproducing highly detailed human expressions, the proposed models seek a balance between expressiveness and simplicity, allowing emotions to be presented in a clear and recognizable manner. This design choice aims to facilitate emotion recognition while maintaining a friendly appearance that encourages interaction and engagement during child-robot activities.

3.2. Platform Workflow

Figure 3 illustrates the operational workflow of ALAN, from system startup to session termination. When powered on, the platform checks whether a name has already been configured. During the first interaction, the child selects a name for the robot, which is stored for future sessions. In subsequent interactions, this step is skipped, and the robot greets the child using the previously assigned name, providing a personalized experience from the beginning of each session.

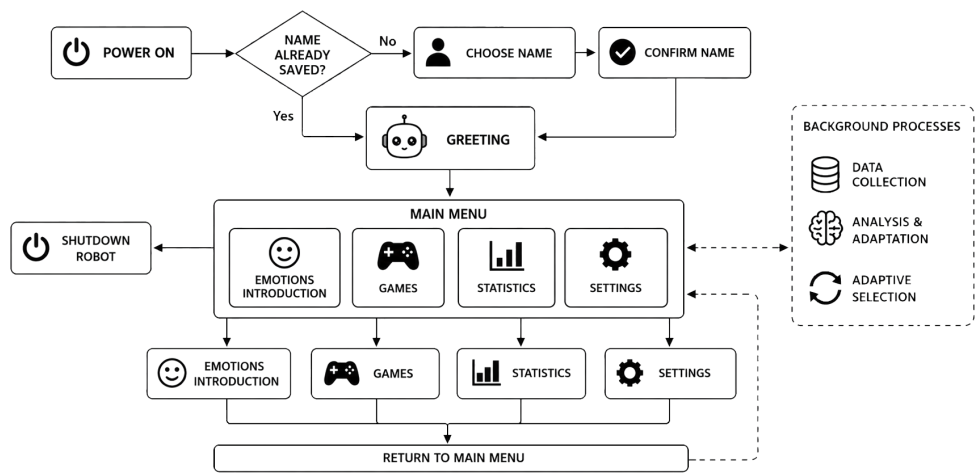


Figure 3: Operational workflow of the ALAN robot, illustrating system initialization and termination, user interaction, educational modules, and adaptive background processes.

After initialization, the child interacts with the graphical interface shown in Figure 4. Before startup, the robot remains in an idle state (Fig. 4a). Once powered on (Fig. 4b), it becomes ready for interaction (Fig. 4c). During the first interaction, the child selects a name for the robot (Fig. 4d), after which the Main Menu is displayed (Fig. 4e), providing access to the educational modules and system settings. The Statistics module (Fig. 4f) enables the child or therapist to monitor performance.

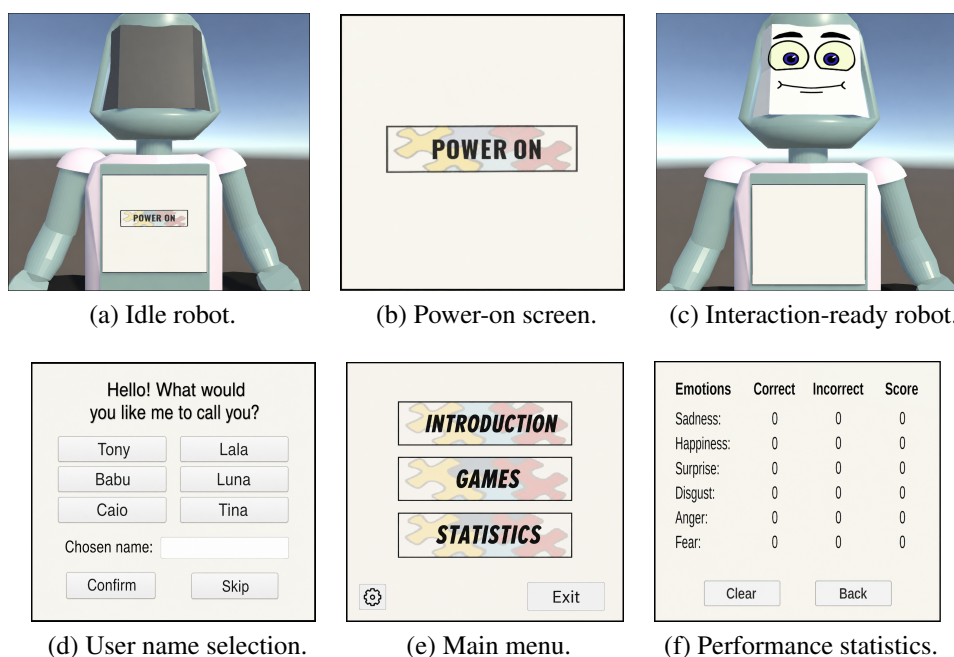


Figure 4: Main interaction screens of the ALAN robot interface.

From the Main Menu, the child may access the educational modules for emotion recognition. The Emotions Introduction module presents the six basic emotions using facial expressions, colour cues, and contextual audio, as illustrated in Figure 5. Each colour identifies a specific emotion, while the corresponding audio message describes a simple everyday situation to reinforce the emotional concept. The colour and audio associations are summarized below:

- **Happiness** (Fig. 5a) - RGB:{255, 215, 88}
"This is my happy expression. I feel happy when you play with me!"
- **Sadness** (Fig. 5b) - RGB:{93, 154, 219}
"This is my sad expression. I feel sad when someone yells at me!"
- **Fear** (Fig. 5c) - RGB:{0, 152, 63}
"This is my fearful expression. I feel scared when I am left alone!"
- **Surprise** (Fig. 5d) - RGB:{175, 214, 244}
"This is my surprised expression. I feel surprised when something unexpected happens!"
- **Disgust** (Fig. 5e) - RGB:{162, 132, 195}
"This is my disgusted expression. I feel disgusted when my screen is dirty!"
- **Anger** (Fig. 5f) - RGB:{255, 84, 62}
"This is my angry expression. I feel angry when someone knocks me over!"

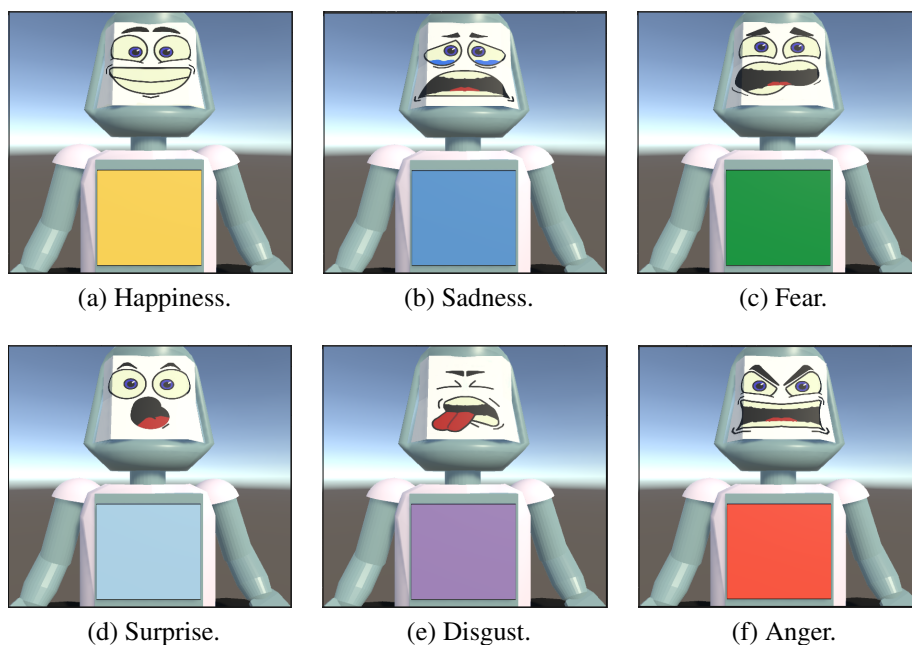


Figure 5: Emotion introduction screens showing the facial expressions and colour associations adopted for the six basic emotions.

Once the introductory activity is completed, the child may proceed to the Games module to practice emotion recognition through interactive exercises. During each round, the robot selects one of the six basic emotions and displays the corresponding facial expression. The child then identifies the displayed emotion using the touch interface, after which the robot provides immediate verbal feedback before presenting the next activity. This interactive process encourages active participation while reinforcing emotion recognition throughout the learning experience.

The Games module contains the interactive activities designed to teach emotional recognition. During gameplay, the robot presents challenges, provides feedback, and encourages the child throughout the learning process. The Statistics module allows the child or therapist to monitor performance indicators, including progress, accumulated achievements, and interaction history. The Settings module provides access to configuration options such as volume, language, brightness, and other system preferences. After completing any of these activities, the system returns to the Main Menu, allowing the child to select another activity or end the session.

Throughout the interaction, a set of background processes operates transparently without interrupting the user experience. The system continuously records interaction data, including responses, response times, scores, and other performance indicators. These data are analyzed to assess the child's performance and identify strengths and difficulties. Based on this analysis, the adaptive learning mechanism updates the probability distribution used to select future emotional activities, increasing the frequency of emotions that present greater difficulty while reducing those that have already been mastered. This strategy personalizes the learning experience according to each child's performance during the sessions without requiring additional user intervention.

Finally, the session can be terminated directly from the Main Menu by selecting the shutdown option. Before powering off, the robot provides a personalized farewell, concluding the interaction in a consistent and engaging manner. This workflow combines intuitive navigation, adaptive learning, and continuous performance monitoring within a unified educational framework designed to support the progressive development of emotional skills in children with ASD during educational interventions.

3.3. Adaptive Educational Framework

The educational component of ALAN was designed to reinforce emotion recognition while supporting personalized instruction based on the child's performance. Rather than presenting emotions in a fixed sequence, it records the results of each game round and uses this information to guide future interactions. Consequently, the learning activities are adapted according to the emotions that are more difficult for the child to recognize, providing a more individualized learning experience.

Each game round begins with selecting one of the six emotions. The robot then transitions from a neutral expression to the selected emotion (see Supplementary Material 2), while the corresponding response options are displayed on the touch interface. To prevent memorization of button locations, emotion labels are randomized every round. The platform reinforces the target emotion through facial expressions, colour cues based on Plutchik's wheel of emotions [Plutchik 1982], and contextual audio describing everyday situations. Figure 6 illustrates a game round in which the target emotion is sadness.

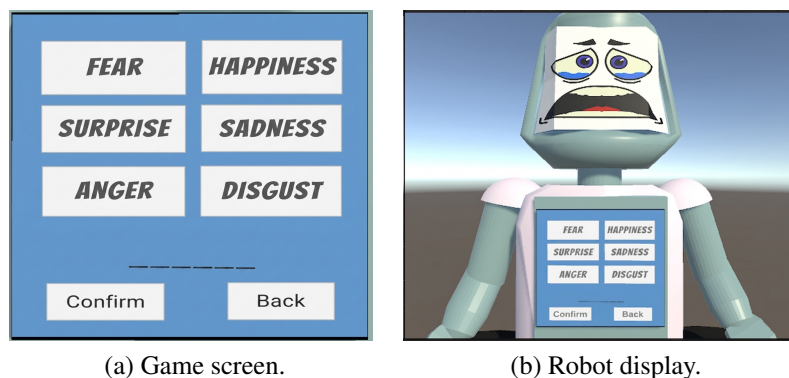


Figure 6: Example of a game round with the selected emotion: Sadness.

After observing the displayed emotion, the child selects one of the available options on the touch interface. The robot then verbally repeats the selected emotion before indicating whether the response is correct or incorrect, providing immediate feedback to reinforce learning, improve accessibility, and maintain user engagement. Once the feedback is delivered, the next game round begins.

An important characteristic of the proposed framework is its ability to collect performance data throughout the interaction. Besides recording whether each response is correct or incorrect, the platform measures the time required to identify each emotion. These data are used to estimate the recognition difficulty of each emotion and maintain a performance history. Based on this information, the platform dynamically increases the frequency of emotions that remain more difficult to recognize.

To further support learning, the platform incorporates a scoring mechanism empirically defined to consider both response accuracy and response time, as described in Table 2. Faster correct responses receive higher scores, whereas longer response times receive lower scores, reflecting greater recognition difficulty. In addition to encouraging efficient responses, this mechanism enables the game to function as both a learning activity and a performance assessment tool.

Table 2: Scoring method based on task completion time.

Elapsed Time (ms)	Score
≤ 6000	100
6001 – 7000	95
7001 – 8000	90
8001 – 9000	85
9001 – 10000	80
10001 – 11000	75
> 11000	70

The adaptive mechanism employed by ALAN is based on a roulette wheel selection strategy. Initially, all emotions are assigned the same weight, resulting in an equal probability of selection. After each interaction, the average score associated with each emotion is used to update the corresponding roulette weights. Specifically, a linear inverse weighting assigns larger weights to emotions with lower average scores, i.e., emotions with lower performance receive larger weights, increasing their probability of being selected in subsequent rounds. Conversely, emotions that are consistently recognized correctly receive smaller weights, reducing their selection probability.

Let $\bar{s}_i$ denote the average score obtained for emotion i , and let $s_{\max}$ be the maximum possible score. The roulette weight assigned to each emotion is computed as

$$w_i = (s_{\max} - \bar{s}_i) + 1, \quad (1)$$

where the constant 1 ensures that every emotion retains a non-zero probability of being selected. The selection probability is then obtained by normalizing the roulette weights,

$$P_i = \frac{w_i}{\sum_{j=1}^6 w_j}. \quad (2)$$

Figure 7 illustrates three examples of the adaptive probability distributions generated by the roulette wheel mechanism. In the initial distribution, all six emotions have equal selection probabilities (16.7%). In the second distribution, disgust receives the highest probability (54.5%) because it has the lowest average score, while the remaining emotions each receive 9.1%. In the third distribution, after happiness is correctly recognized with the maximum score, its selection probability is reduced to approximately 3.0%, whereas the probabilities of the remaining emotions increase to approximately 19.4%. These examples illustrate how the roulette continuously updates the selection probabilities according to the child's performance.

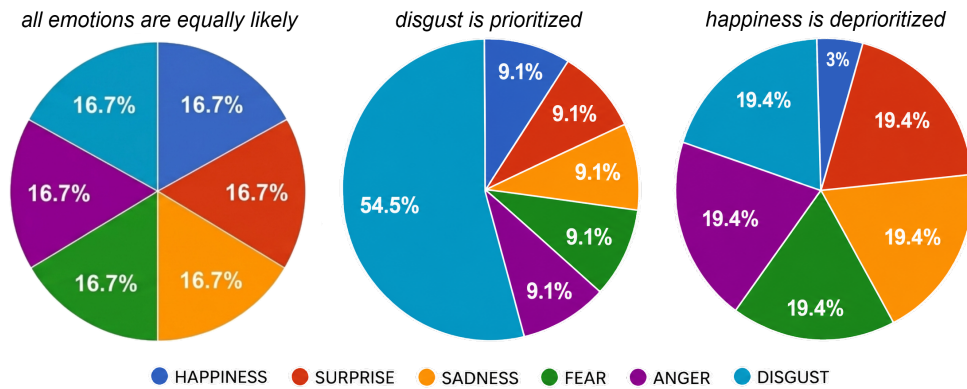
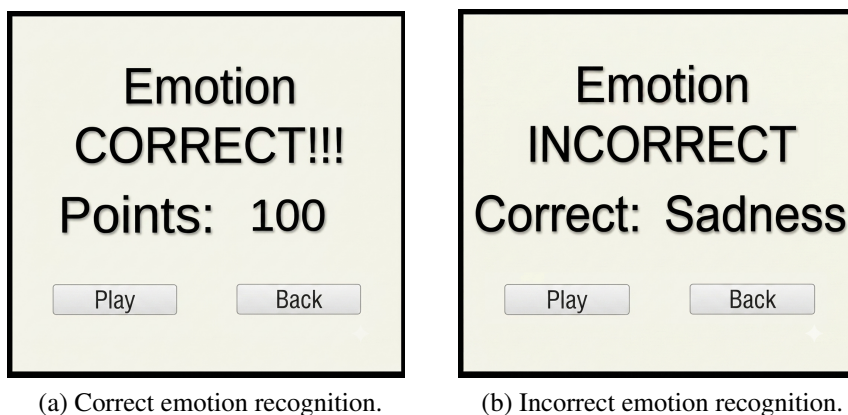


Figure 7: Examples of roulette probability distributions generated by the adaptive mechanism. The initial distribution assigns equal probabilities to all emotions, while subsequent distributions adjust the probabilities by prioritizing Disgust and deprioritizing Happiness.

Since the roulette weights are continuously recalculated from the accumulated performance history, the probability distribution evolves throughout the interaction. Consequently, emotions that require additional practice are presented more frequently, while those already recognized successfully continue to be selected with lower probability, ensuring continued reinforcement without eliminating previously learned emotions.

At the end of each round, the robot provides immediate feedback on the user's performance. For correct answers, the platform displays a success message and returns to the neutral expression. For incorrect answers, the robot presents the correct emotion with its facial expression and explanatory audio. This strategy reinforces the association between facial expressions and emotions while updating the interaction history. Figure 8 illustrates examples of the feedback screens.



(a) Correct emotion recognition.

(b) Incorrect emotion recognition.

Figure 8: Examples of feedback after correct and incorrect emotion recognition.

The proposed strategy transforms the game from a static emotion recognition activity into a personalized learning environment. By continuously adapting the probability of each emotion according to the child's performance, ALAN concentrates practice on emotions that remain difficult to recognize while reducing the repetition of those already mastered. Consequently, the interaction evolves over time, allowing the teaching process to adapt to each child's learning profile.

4. Qualitative Assessment

Emotional expressiveness is a central design element of ALAN. The facial models represent the six basic emotions and employ animated transitions to create smoother and more natural interactions. In addition to facial expressions, the association between emotions, colours, and contextual audio cues provides multiple channels through which emotional concepts can be presented and reinforced. This multimodal approach may facilitate emotion recognition by allowing users to associate emotions with different visual and auditory stimuli more effectively during the learning process.

The educational games complement these interaction mechanisms by reinforcing emotion recognition through active participation. By requiring users to identify emotions based on facial expressions and contextual information presented by the robot, these activities are intended to promote engagement while providing immediate feedback throughout the learning process. Furthermore, the platform architecture supports adaptive strategies based on user performance, creating opportunities for personalized interventions tailored to individual learning needs.

Despite these capabilities, the adaptation strategy currently relies exclusively on performance metrics collected during educational games. Although this approach enables personalized content selection, it does not consider the child's affective or attentional state. Integrating multimodal perception, such as facial expression analysis, gaze estimation, or physiological signals, could improve user modelling and support more effective adaptation. Future versions could also incorporate gestures and other non-verbal behaviours to enhance the naturalness of human-robot interaction.

5. Conclusion and Future Work

This work presented ALAN, an adaptive robot for teaching emotional skills to children with autism spectrum disorder². The proposed platform was designed as a socially assistive robot that integrates animated facial expressions, audio feedback, colour-based emotional cues, and educational games into a unified environment for emotion learning. By combining multimodal interaction with educational activities centred on the six basic emotions, ALAN provides a flexible framework intended to support emotion recognition and emotional skills development in educational and therapeutic contexts.

The proposed platform incorporates animated facial transitions, multimodal emotional feedback, and an educational game designed to reinforce emotion recognition through active child-robot interaction. Unlike approaches that emphasize individual aspects of interaction, ALAN integrates educational, social, emotional, and adaptive resources within a single robotic platform. This integrated design represents a step towards more comprehensive robotic tools for emotional skills training.

Future work includes: (i) evaluating the effectiveness of ALAN in supporting emotion recognition and emotional skills development through structured intervention sessions; (ii) defining and analysing quantitative and qualitative evaluation variables, including emotion recognition accuracy, response time, user engagement, and interaction patterns; and, (iii) extending the adaptive mechanisms to personalize educational activities according to individual user performance and learning progress.

² Available at: <https://github.com/claudiney-tinoco/robot-alan>. Accessed on: July 20, 2026.

Acknowledgements

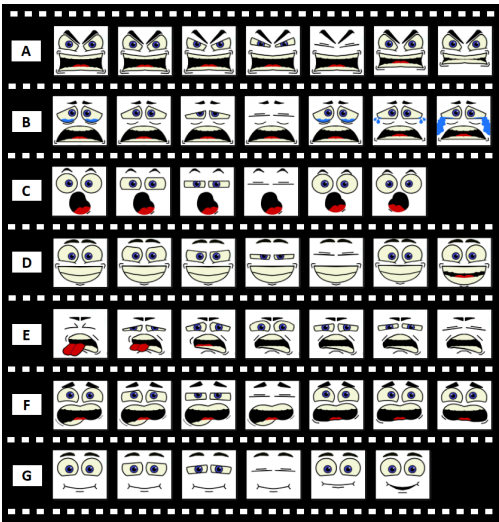
This work was supported by FAPEMIG, FAPERJ, CNPq and CAPES.

Statement on the use of Generative AI

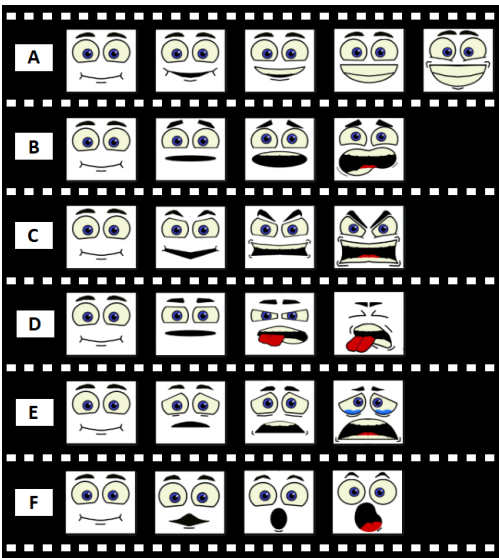
The authors used Generative AI tools only for language polishing and clarity improvement. The authors retain full responsibility for the scientific content of this work.

Supplementary Material

1. Representative animation frames illustrating the facial expressions used for each emotion: (A) Anger; (B) Sadness; (C) Surprise; (D) Happiness; (E) Disgust; (F) Fear; and, (G) Neutral expression.



2. Representative frames of the transitions from the neutral expression to each emotion: (A) Neutral-to-Happiness; (B) Neutral-to-Fear; (C) Neutral-to-Anger; (D) Neutral-to-Disgust; (E) Neutral-to-Sadness; and, (F) Neutral-to-Surprise.



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