EDUCATIONAL ROBOT WITH ARTIFICIAL INTELLIGENCE TO PROMOTE SOCIAL-EMOTIONAL LEARNING IN CHILDREN WITH AUTISM

ROBOT EDUCATIVO CON INTELLIGENZA ARTIFICIALE PER FAVORIRE L'APPRENDIMENTO SOCIO-EMOZIONALE NEI BAMBINI CON AUTISMO

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ABSTRACT
In recent years, the significant progress of technologies based on AI has revolutionized the field of emotion recognition, opening new horizons in the interpretation and analysis of human expression. This progress promises the personalized educational applications that help children with autism recognize emotions by mimicking facial expressions associated with specific feelings. The project aims to develop a robot integrated with AI algorithms to foster socio-emotional skills in children with autism.

Negli ultimi anni, il progresso delle tecnologie basate sull'intelligenza artificiale ha rivoluzionato il campo del riconoscimento delle emozioni. Tale progresso ha permesso lo sviluppo di applicazioni educative personalizzate per assistere i bambini autistici nel riconoscimento delle emozioni mediante l'imitazione delle espressioni facciali. Il presente progetto si propone di sviluppare un robot dotato di algoritmi di intelligenza artificiale per promuovere le abilità socio-emozionali nei bambini autistici.

KEYWORDS
Artificial Emotional Intelligence, Emotion Recognition, Autism Spectrum Disorder, Educational Robot, social skills.
Intelligenza Artificiale Emotiva, Riconoscimento delle emozioni, Disturbo dello Spettro Autistico, Robot Educativo, Abilità sociali.

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Introduction

In recent years, the advancement of technologies based on artificial intelligence has produced a significant revolution in the field of human emotion recognition. This progress has opened new perspectives in the world of interpretation and analysis of human expressions, providing fertile ground for the development of innovative and promising solutions. Through the application of sophisticated artificial intelligence algorithms capable of processing complex data from various sources such as images, videos, and vocal signals, it's possible to probe deeper into individuals' emotional states. In the educational and pedagogical context, emotional components play a crucial role in determining students' academic performance, as they influence their cognitive abilities and motivation to learn. Various studies have shown how affective aspects modulate mental processes such as memory, attention, problem-solving ability, and school outcomes (Loderer et al., 2019; Pekrun et al., 2017). These studies have highlighted that emotions can manifest both as a consequence of learning processes and as their precursors, exerting a significant influence on the underlying cognitive mechanisms. Therefore, pre-existing emotions or the anticipation of future successes or failures can modulate the cognitive processes involved in learning (Marcos-Merino et al., 2021). Similarly, the positive emotions from the results achieved by students can impact their future emotions (Putwain et al., 2018). Lucangeli (2019) illustrates the connection between emotions and learning processes with the concept of Warm Cognition. According to Lucangeli, we not only acquire and store information but also record the emotions that accompany such experiences. Hence, learning is not merely a process of data assimilation but is also deeply modulated by the emotional responses that such information elicits, thereby influencing memory retention and retrieval. This approach emphasizes the significant role of emotions in educational processes and suggests that educators and teachers should pay attention not only to the transmission of knowledge but also to the creation of positive emotional experiences. For this reason, it is essential that both teachers and students are able to identify, understand, and manage their emotions and behaviors to optimize teaching strategies and enhance learning effectiveness.

In this context, the use of artificial intelligence-based technologies offers the opportunity to develop personalized educational solutions that not only help teachers identify and monitor students' emotional variations but also provide them with targeted emotional and psychological support. In recent years, the importance of the role of emotions in education and learning has been increasingly recognized and valued. Particularly, there has been growing interest in using artificial intelligence as a supportive tool in the education of children with autism spectrum disorders (ASD). Children with autism often do not develop the ability to recognize and accurately interpret their own emotions and those of others to the same extent as their peers. This difficulty can lead to significant challenges in communication and social interaction, affecting the child's ability to fully participate in daily life and build meaningful relationships. The inability to identify and understand emotions can also affect emotional regulation, making it more difficult for children with autism to effectively manage their emotional responses to stressful or new situations. To address these challenges, innovative educational tools can be created to promote the development of socio-emotional skills in children with autism. In this scenario, the project aims to develop an open-source robotic system integrated with artificial intelligence algorithms that can act as an interactive pedagogical tool, encouraging children with ASD to improve their communication and social interaction skills. The project's purpose is to provide teachers with a support tool that allows them to design individual activities and subsequently extend the activity to the entire class. This system not only offers a personalized and adaptable approach to the specific needs of each child but also represents an opportunity to explore new horizons in human-machine interaction research and the application of artificial intelligence in the field of inclusive education.

1. Artificial Emotional Intelligence in educational contest

In the educational context, the adoption of advanced technologies such as artificial intelligence (AI) systems marks a significant advancement in monitoring and analyzing students' emotional responses. This technology can provide a deep and immediate understanding of students' reactions by detecting variations in facial expressions that may indicate frustration, confusion, or satisfaction during learning processes. Emotions play a crucial role in the learning process as they affect perception, memory, attention, and consequently, academic success. In other words, emotions represent a complex system of interactions between subjective and objective factors, which can give rise to affective experiences, generate cognitive processes, and influence behavior. Research shows the interconnection between emotion and cognition, where emotions significantly impact learning processes and behavior regulation (Bower & Cohen, 1982; Phelps, 2006; Woolf et al., 2009). Salovey and Mayer (1990) introduced the concept of Emotional Intelligence (EI), highlighting the connection between emotion and cognition and defining it as the ability to perceive, understand, and manage emotions in oneself and others. Further studies by Qualter and colleagues (2007) indicate that EI is correlated with life success, including academic performance. Therefore, these studies underscore the relevance of emotional and cognitive components in learning, suggesting the importance of a multidimensional analysis for a holistic assessment of the educational experience. For this reason, Affective Computing (AC) technology has also been applied in educational and teaching contexts to allow for precise customization of educational interventions aimed at enhancing students' emotional well-being. AC can be used to develop systems that can detect emotions through facial expressions, voice analysis, and other modalities, with the goal of improving the effectiveness of learning and the overall educational experience. Some research, such as that conducted by Ezquerra and colleagues (2022), has sought to integrate the effectiveness of AI in monitoring and analyzing emotional and behavioral dynamics in a real educational context. The scholars conducted an experiment to analyze the impact of emotions and behaviors during an Inquiry-Based Science Education (IBSE) activity, which aimed to stimulate changes in students' emotional and behavioral states using artificial intelligence for facial expression recognition. During the experiment, cameras were positioned to capture students' facial expressions and actions as they engaged in the activity. The recorded videos were subsequently analyzed using iMotions® software, which processes images to identify facial expressions associated with specific emotions. In particular, the software tracks 34 reference points on each student's face and uses the Affectiva AFFDEX® algorithm to analyze the expressions and deduce the associated emotions. Through these data, it was possible to examine how the various phases of the activity influence students' emotional responses. Other studies, such as those conducted by Mejbri and colleagues (2021), have implemented conversational agents and affective tutoring systems in e-learning contexts to simulate human interactions and appropriately respond to users' emotional states. Therefore, Affective Emotional Intelligence (AEI) offers the possibility to overcome the limitations associated with traditional methods of observation and data collection by implementing emotion recognition software, which represents a significant breakthrough in understanding social interactions and learning strategies. This increasing level of precision in identifying and interpreting human emotions by AI systems has opened new opportunities in the field of social interaction and personalized learning.

2. Affective computing to support Children with autism

Emotional Artificial Intelligence (EAI) or affective computing is a field of artificial intelligence that focuses on developing systems capable of recognizing, processing, and simulating human emotions. The concept of affective computing was first introduced by Rosalind Picard, who described it as “computing that relates to, arises from, or influences emotion” (Picard, 1995). Picard argues that for computers to interact effectively with humans in real-world contexts, they must be able to recognize and express emotions. This idea is linked to research in neuroscience, particularly the studies by Damasio (1994), which highlight how emotions are crucial in human judgment and decision-making processes; traditionally, studies on decision-making have favored cognition, namely the ability to process thoughts. Since the 1990s, there has been a growing awareness of the significant impact of affect on human decision-making. Specifically, Rosalind Picard in her article introduced the concept of affective computing detailing levels ranging from the unconscious computation of emotions to fully affective systems. These levels vary from Level 0, where computers lack the capability to recognize or express emotions, leading to impersonal interactions, to Level 1, where computers can express but not recognize emotions, applicable in scenarios like virtual training avatars that motivate users. Level 2 implies that computers recognize human emotions without responding emotionally, able to adapt tasks based on the user's emotional state during interactions such as computer-based training. The most advanced stage, Level 3, features computers that recognize and express emotions, aiming for more natural interactions, though they still lack a deeper, personalized emotional understanding (Picard, 1995). Computing solutions capable of simulating affection, classified as Level 1, play a crucial role in influencing human behavior through the generation of positive emotions capable of evoking feelings that can motivate a person to persevere in a task that might otherwise appear boring (Richardson, 2020). For example, a virtual avatar within a computer-based training program might express joy when a user successfully completes a complex module, thereby encouraging the person to continue in the training pathway. However, these solutions operate based on predetermined assumptions about which emotion might be most effective in a given context, without considering the actual emotional conditions of the involved subject. In other words, the system is not able to detect whether the user is actually bored or excited but merely provides an emotional response that may not always be the most appropriate. This lack of sensitivity to the real emotional states of users makes such technologies useful in situations where a generalized emotional response is sufficient. With the introduction of cognitive algorithms, there has been significant progress in recognizing and assessing human emotions, paving the way towards more sophisticated interactions that mimic human ones (Richardson, 2020). Such advancements have made machines capable of understanding and responding to affective states in an increasingly natural manner, significantly improving human-machine interaction in fields such as education and therapy. In the field of education, affective computing is primarily finding application in monitoring the attention and emotions of students. In China, for example, cameras have been installed at the front of classrooms to analyse students every 30 seconds (Thubron, 2018). These devices alert the teacher if a student's attention level falls below a pre-set threshold. In the United States, similar technologies are employed during computer tutoring sessions, where webcams record students to identify levels of engagement or frustration (Knight, 2013). These tools are designed to help teachers optimize teaching methodologies and interaction with students by personalizing the educational approach based on the individual needs of each student. Indeed, such systems based on Emotional Artificial Intelligence (EAI) have proven particularly promising in supporting children with autism, as they can facilitate social interaction and help break down the communication barriers characteristic of the disorder. In educational and therapeutic contexts, this technology can be especially useful for educators, as it allows for accurate study of perception, interpretation, and response to emotions in children with autism. The technology itself is not a single sufficient factor to generate improvement, but it is essential to consider reference theories, such as Baron-Cohen's theory, which shows important implications for the use of affective computing with autistic children. In his 2002 article "The extreme male brain theory of autism," Baron-Cohen explores gender differences in cognition and proposes a theory on the neurological bases of autism. According to Baron-Cohen, there are two significant cognitive dimensions, empathy and systemizing, which tend to differ between the sexes. Specifically, females generally show greater empathy, while males exhibit greater systemizing ability. This perspective suggests that autism can be seen as an extreme manifestation of the "male brain," where the ability to systemize is highly developed at the expense of empathy. This theory is supported by studies showing that people with autism have marked abilities in fields requiring a high level of systemization but face difficulties in social interactions, which require empathy. Therefore, affective computing tools, which help recognize and respond to human emotions, could be particularly useful in compensating for the empathy difficulties in children with autism, facilitating their social interaction. Moreover, the use of systems capable of adapting and reacting to specific behavioral needs can improve the management of educational environments for children with autism, personalizing education according to their specific needs. An example is given by the research conducted by Sivasangari and colleagues (2019), which focuses on the use of advanced technologies to assist people with Autism Spectrum Disorder (ASD) who encounter difficulties in communication and social interaction, even with familiar figures. Sivasangari and colleagues use an approach that employs the identification of individuals and the recognition of their emotions through the combined use of sensors and machine learning algorithms. Specifically, the proposed system utilizes a neurological sensor to collect EEG data, which monitors brain activity, and a Q sensor to measure stress levels. Additionally, it integrates facial recognition for emotion identification. The research results show that the system can detect emotions with good accuracy, demonstrating its effectiveness in providing support to individuals with ASD. Additionally, affective computing has evolved with advances in machine learning, particularly in fields like computer vision and natural language processing, driving significant progress in how computers interpret and respond to human emotions. Other studies also focus on how EAI can be integrated into wearable devices that monitor physiological signals of children to predict and manage episodes of stress or sensory overload, as explored by Goodwin and colleagues (2019). In his studies, Goodwin explores the use of a wearable biosensor to predict aggressive episodes in youth with Autism Spectrum Disorder (ASD). Worn on the wrist, the biosensor collects peripheral physiological and motion data to identify early signs of aggression, enabling timely interventions aimed at mitigating such behaviors. The results show that aggression can be predicted with relatively high accuracy, suggesting the potential of these devices to improve the management and intervention in problematic behaviors of people with ASD. In other words, these tools can provide immediate feedback to educators and therapists, allowing them to adapt intervention strategies in real-time. Therefore, emotional artificial intelligence technologies aim to enhance the quality of life of children with autism, facilitating the understanding of their emotional experiences and encouraging social interaction. This technology opens up new possibilities for more effective educational and behavioral therapies, offering specialists new ways to interact with and understand children with autism.

3. Design of an AI integrated robot

As mentioned in the previous paragraph, some research has explored how technologies based on Emotionally Intelligent AI (IAE) can improve the communication and social interaction of children with autism, providing tools that support them in identifying and expressing emotions (Sivasangari et al., 2019; Goodwin et al., 2019). These advanced technologies may include applications that use virtual avatars or robots capable of recognizing emotions to interact more intuitively and accessibly with children. Specifically, in the field of robotics, there are practical applications of affective computing such as the Pepper robot, which can converse and detect certain human emotions. Another example is Sofia, a social humanoid robot developed by Hanson Robotics in 2016. Sofia is capable of mimicking human gestures and expressions, managing to support simple conversations on predefined topics. A social robot, to support children with autism, should have the following characteristics: 1) Modularity, which allows a focused approach on specific aspects to gradually adapt to the needs of the children; 2) Configurability, as it can express various facial expressions, adjusting the intensity to avoid sensory overload in children; 3) Sociability, namely being "imperfect" to maintain realistic expectations and not demotivate the children; 4) Agency, equipped with the ability to adapt to the educational context (Pennazio, 2019). This approach aims to offer targeted and sensitive support to the needs of children with autism, facilitating learning and communication in an educational context.

In light of these considerations, an emotion recognition software has been developed to be integrated into an open-source robot, with the goal of detecting the user's emotions through the identification of facial expressions. The purpose of the project is to foster the development of social skills in children with autism spectrum disorders by creating a robot equipped with artificial intelligence algorithms capable of identifying emotions and providing immediate feedback during interactions with users. This software employs multimodal artificial intelligence to accurately analyze facial expressions via a webcam positioned on the robot's face (Figure 1). The robot was designed using Rhinoceros CAD software and physically realized through 3D printing using a Prusa MK3S printer, to ensure a high level of precision and customization (Schiavo et al., 2024). During interaction with the robot, children are engaged in an interactive learning environment, designed to stimulate and develop their emotional recognition abilities. The training activities have been designed to meet the specific needs of children with autism spectrum disorders, employing techniques that include imitation of emotional expressions and receiving immediate feedback. These training activities are based on a playful-educational approach, making learning more engaging and fun. For example, the robot can express a variety of emotions through facial expressions, inviting children to guess the emotion represented. Then, the robot offers children the opportunity to imitate the emotional expression shown, providing them with immediate and constructive feedback. This bidirectional exchange not only helps children refine their ability to interpret and reproduce emotional expressions but also helps to strengthen their sense of self-esteem and self-efficacy. Through imitation, children learn to identify and interpret different emotional expressions through facial expressions, voice tones, and body language. This learning process proves to be extremely effective, as it provides children with a concrete model to follow, thus facilitating the understanding and assimilation of various emotional expressions. Interaction with the robot goes beyond mere imitation and becomes a real educational game, in which the robot acts as a social mediator and adventure companion, encouraging interaction, reducing feelings of isolation, and promoting the development of interpersonal skills in children with ASD. The project employs a methodological approach inspired by Design-Based Research (DBR), which promotes the development of practical and effective solutions through iterations of design, implementation, and evaluation within the **real** learning context. This approach emphasizes the importance of personalized education and inclusive learning environments, highlighting the crucial role of innovative technologies in significantly contributing to the wellbeing and learning of all students.

During interaction with the robot, children are engaged in an interactive learning environment, designed to stimulate and develop their emotional recognition abilities. The training activities have been tailored to meet the specific needs of children with autism spectrum disorders, utilizing techniques that include the imitation of emotional expressions and receiving immediate feedback. In particular, the software has been trained based on Patricia Howlin's program to exercise autistic children in developing the mentalization process. This process is crucial to help children understand that others have beliefs, desires, and intentions that are different from their own. By using this approach, the software aims to improve the theory of mind capabilities, which are essential for social interactions and understanding others' emotional and cognitive dynamics. For example, the child can interact with the software through a vocal system or via chat, and the tasks proposed are based on the social stories included in Patricia Howlin's program. These stories are designed to help the child identify the emotions the characters are experiencing at that moment, inviting the child to imitate such emotions. Subsequently, the child will receive immediate and constructive feedback, specifying whether the response is correct or not. This bidirectional exchange not only helps children refine their ability to interpret and reproduce emotional expressions but also helps strengthen their sense of self-esteem and self-efficacy. Through imitation, children learn to identify and interpret various emotional expressions through facial expressions, voice tones, and body language. This learning process proves to be extremely effective, as it provides children with a concrete model to follow, thus facilitating the understanding and assimilation of various emotional expressions. Interaction with the robot goes beyond mere imitation and becomes a real educational game, in which the robot acts as a social mediator and adventure companion, encouraging interaction, reducing feelings of isolation, and promoting the development of interpersonal skills in children with ASD. The project employs a methodological approach inspired by Design-Based Research (DBR), which promotes the development of practical and effective solutions through iterations of design, implementation, and evaluation within the real learning context (Juuti & Lavonen, 2006). This approach emphasizes the importance of personalized education and inclusive learning environments, highlighting the crucial role of innovative technologies in significantly contributing to the wellbeing and learning of all students.

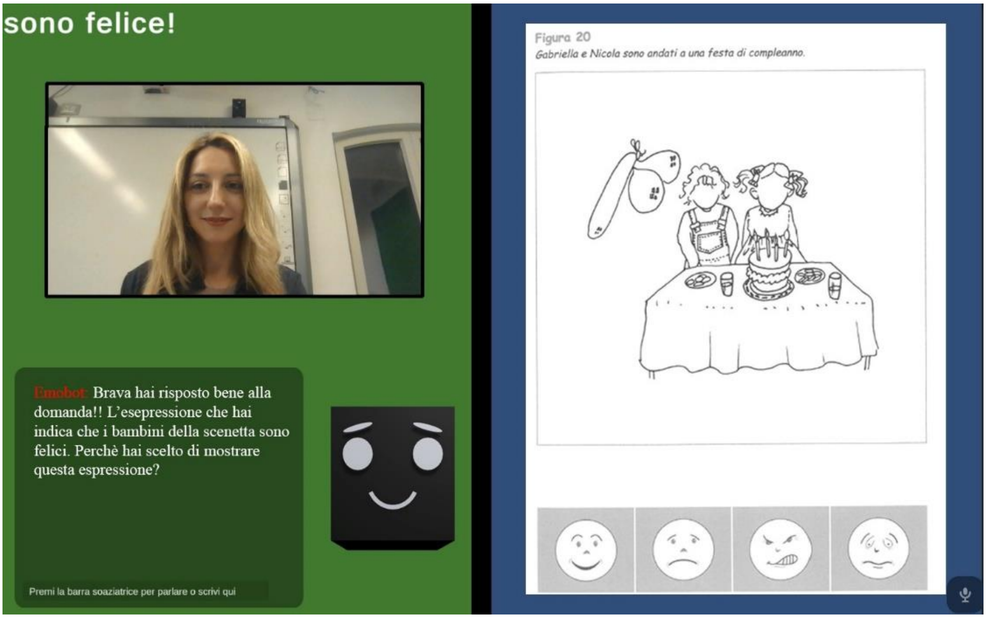

Figure 1: Software based on the Howlin program

Conclusions

Artificial Intelligence (AI) opens promising perspectives for the development of innovative and personalized educational applications that can dynamically adapt to individual students and the school context. However, critical reflections on the impersonal nature of algorithm-mediated learning emerge, as it can overlook the essential dimension of human interaction, crucial for the socio-emotional development of students. In this context, the role of the teacher becomes irreplaceable, acting as a catalyst for learning, capable of instilling in students not only knowledge but also human values, empathy, and emotional support. In the educational field, the branch of artificial intelligence known as affective computing has proven particularly effective in improving communication and social interactions in children with autism, as these systems are able to detect human emotions and provide contextually appropriate responses. However, there are limitations to current algorithms, such as Paul Ekman's Facial Action Coding System (FACS), which presuppose the existence of universal emotions manifested by specific facial muscle movements. Recent studies have shown that such expressions are correctly interpreted only 20-30% of the time (Barrett, 2017), suggesting that context is essential for the correct interpretation of emotions. Similarly, text-based sentiment analysis shows biases and limitations, as algorithms created using dictionaries that categorize words based on sentiments have highlighted racial biases, since they do not account for cultural differences in the use of language to express emotions (Sap et al., 2019). Although artificial intelligence offers extraordinary possibilities to personalize education and improve the communication skills of children with autism, maintaining a balance between technology and human interaction is fundamental. The teacher plays an irreplaceable role in educating and supporting students on an emotional and social level.

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