

Integrating Social Robotics into School AAC Practices: A Hybrid Architecture for Pedagogically Mediated Communicative Participation

Luiziane Paulino dos Santos¹, Raul Benites Paradedá¹

¹Graduate Program in Computer Science

State University of Rio Grande do Norte (UERN)

Federal Rural University of the Semi-Arid Region (UFERSA)

St. Professor Antônio Campos – BR 110 km 48 – Mossoró – RN – Brazil – 59600-000.

luiziane20261002887@alu.uern.br, raulparadedá@uern.br

Abstract. *Functional use of Augmentative and Alternative Communication (AAC) by students with Autism Spectrum Disorder (ASD) remains a central challenge in Multifunctional Resource Rooms. This article presents a hybrid system integrating the NAO robot as a pedagogical mediator into existing school AAC practices. Built under the Design Science Research framework, the system addresses the technical heterogeneity among the AAC resources already in use by students. Applied across ten sessions with three children with ASD, with teachers co-planning all interactions, results showed progression in autonomous AAC use, including generalization to natural contexts such as the school's Science Fair. This suggests integrating social robotics with existing practices is a productive path toward inclusive participation.*

1. Introduction

The inclusion of students with Autism Spectrum Disorder (ASD) in regular schools demands more than physical access to educational spaces: it requires concrete conditions for communicative participation, pedagogical engagement, and meaningful learning [Moraes et al. 2023]. To address this, Multifunctional Resource Rooms (MRRs) have incorporated Augmentative and Alternative Communication (AAC) resources into their pedagogical practices, including physical boards, picture albums, and digital applications, as tools to support functional communication in students with absent or limited speech.

However, the availability of these resources does not, by itself, guarantee their functional appropriation. Many students with ASD resist incorporating AAC into their communicative routine, preferring idiosyncratic gestures or restricted forms of pointing [NUNES et al. 2021], representing a concrete challenge for MRR teachers who often lack strategies capable of motivating consistent and spontaneous resource use in real school contexts.

Social robotics has been identified as a promising complementary strategy for communicative interventions with children with ASD, given that humanoid robots offer predictable, repeatable, and less socially demanding interactions [Scassellati et al. 2012]. Despite this potential, existing studies predominantly treat robotic systems and AAC resources as independent parallel modules, without technical or pedagogical integration between them [dos Santos and Paradedá 2026], limiting the potential of both approaches.

This work departs from a concrete situation encountered in an MRR: three children with ASD who resisted the functional use of their respective AAC resources, none of which were technically compatible with direct robotic integration. Rather than replacing these resources or treating technological incompatibility as a peripheral obstacle, this work treats it as the central design problem, and its resolution as a necessary condition for social robotics to function as a genuine pedagogical mediator in inclusive educational contexts.

This article describes the design, architecture, and preliminary educational applicability of a hybrid system that integrates the NAO robot with the AAC resources already in use by the participants, developed within the Design Science Research (DSR) framework [Dresch et al. 2014][Hevner et al. 2004]. The main contributions are threefold: (1) a hybrid architecture that bridges heterogeneous AAC formats with robotic interaction without replacing established pedagogical practices; (2) evidence that co-planned, personalized robotic mediation with active teacher participation supports the development of autonomous AAC use; and (3) preliminary evidence of generalization of communicative competence to natural school contexts, including autonomous participation in a Science Fair. To our knowledge, this is the first work to treat format heterogeneity in school-based AAC resources as an explicit design constraint for pedagogically integrated robot-mediated communication systems.

2. Theoretical framework and Related Works

ASD is characterized by deficits in social communication and restricted behavioral patterns [APA 2022], with communication barriers representing the primary obstacle to full school inclusion [Moraes et al. 2023]. Inclusion, in its substantive sense, demands communicative participation, the student's effective capacity to initiate, maintain, and respond to communicative exchanges in relevant situations [Light and McNaughton 2014], which cannot be dissociated from the mediating role of professionals involved.

AAC encompasses strategies and resources for individuals with absent or limited speech [Nunes and Walter 2020]. The Picture Exchange Communication System (PECS) [Bondy and Frost 1994] and its adapted version [Walter 2000], the reference methodology in the participating MRRs, have demonstrated gains in expressive vocabulary and communicative initiative [Beukelman et al. 1998]. Nevertheless, students who communicate through gestures tend not to incorporate communication boards spontaneously [NUNES et al. 2021], requiring intentional mediating strategies in which the teacher actively constructs situations where AAC use becomes purposeful [Light and McNaughton 2014]. Social robotics has emerged as a complementary motivational strategy: its effectiveness derives not from the device's intrinsic capabilities, but from the personalization of interactions based on individual stimuli [dos Santos and Paradedá 2026], consistent with mediated learning theory [Feuerstein et al. 1981].

Recent reviews [Bartl-Pokorny et al. 2021][dos Santos and Paradedá 2026] identify the NAO as the dominant platform in interventions with autistic children, with reported gains in social communication and imitation skills [Alnafjan et al. 2024]. A critical gap across these studies is twofold: none address the role of the teacher in constructing and sustaining personalization, and none treat the technical heterogeneity of AAC formats

present in real school contexts as a design constraint. This work addresses precisely this gap, proposing a model in which social robotics functions as a pedagogical mediator integrated into the AAC practices already established in the school context, with teacher participation as a structural, not auxiliary, component.

3. Methodology

This research adopts a qualitative, exploratory, and applied approach grounded in the Design Science Research (DSR) framework [Dresch et al. 2014][Hevner et al. 2004], structured in iterative stages: problem identification, definition of objectives, design and development, demonstration, evaluation, and communication [Peppers et al. 2007]. The study was approved by the Research Ethics Committee (opinion no.7,799,535), and the legal guardians of all participants signed the Informed Consent Form.

3.1. Participants and context

Three children enrolled in the MRR of a private school were selected according to pre-defined criteria: difficulty with verbal communication, resistance to functional AAC use, and ability to remain in the environment for at least 15 minutes. Table 1 presents the participant profiles.

Table 1. Participant profiles

Participant	Age	Diagnosis	Gender	Grade	Communication mode
ID 1	8 years	ASD grade 2 / Apraxia of speech	Female	3rd grade	Speech
ID 2	12 years	ASD grade 3	Male	6th grade	Gestures and pointing
ID 3	14 years	PDD / Dysphasia	Male	8th grade	Physical gestures

Profile analysis revealed a critical heterogeneity in the AAC resources in use. Participant ID 1 used a physical board with printed pictograms. Participant ID 2 had a tablet-based AAC application that was technically operational but effectively unusable: pictogram categories did not reflect the student's routine and images were displayed in English, a language with no functional meaning for the participant. Participant ID 3 used TD Snap on iOS, which provides no open API for external integration. This heterogeneity motivated two architecturally distinct systems: a QR code recognition system for participants ID 1 and ID 2, and a digital auxiliary board for participant ID 3.

3.2. System design and architecture

3.2.1. QR code recognition system

QR code was selected over alternatives such as RFID and AI-based computer vision due to its reliability, low cost, deterministic reading, and ease of modification by education professionals without technical knowledge. Cards were constructed with pictograms from ARASAAC¹, each associated with a keyword and QR code. Following preliminary tests, reflective surfaces were eliminated: the final model adopted a matte front with pictogram and word, and a QR code enlarged by 30% on the back (Figure 1). Cards for the robot were laminated with magnetic fastening on arm supports, associating speech with visual stimulus during interaction.

¹Aragonese Centre of Augmentative and Alternative Communication. Available at: <https://arasaac.org>. Accessed: March 1, 2026.

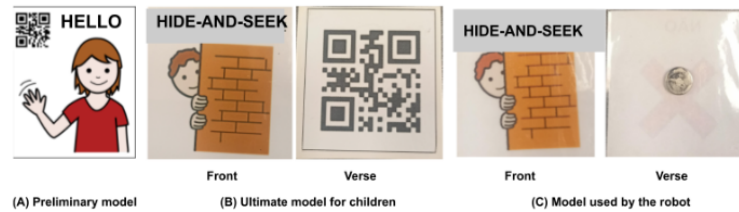


Figure 1. Model of the cards made during the study. (A) model used for validation; (B) model after being redesigned and used during the study by the children and (C) model of the card used by the robot in the interactions.

Reading was implemented via the NAOqi ALBarcodeReader service, which continuously monitors the robot's front camera and notifies when a code is detected. The reading position was calibrated at an ideal distance of 12 to 15 centimeters, with the robot's head in a fixed position and maximum rigidity configured to prevent involuntary movements. The system integrated nine NAOqi services across five functional categories: perception, handled by ALBarcodeReader for QR code reading and ALBasicAwareness for spatial awareness; communication, through ALTextToSpeech and ALMemory; movement control, via ALMotion and ALRobotPosture; visual feedback, using ALLeds and ALBackgroundMovement; and autonomous behavior management through ALAutonomousLife.

To illustrate, a typical interaction unfolds as follows: the robot begins with a greeting and contextualizes the activity (e.g., coloring, or cutting and pasting); the child then holds up a card corresponding to the current activity toward the robot's camera; upon successful detection of the QR code, the robot hands over the requested item (if the context involves an item request) and advances the dialogue to the next communicative stage.

If no valid code is detected or an unexpected card is presented, the robot does not directly correct the child. Instead, it initiates a three-level structured support sequence: first, a friendly non-verbal signal—via an LED expression—invites a retry; if this does not resolve the situation, a category-related verbal hint narrows the scope of the expected response; and, if necessary, the robot explicitly rephrases the question. Throughout this sequence, the MRR teacher remains present to demonstrate card usage when needed, ensuring the child is never left without support (Figure 2).

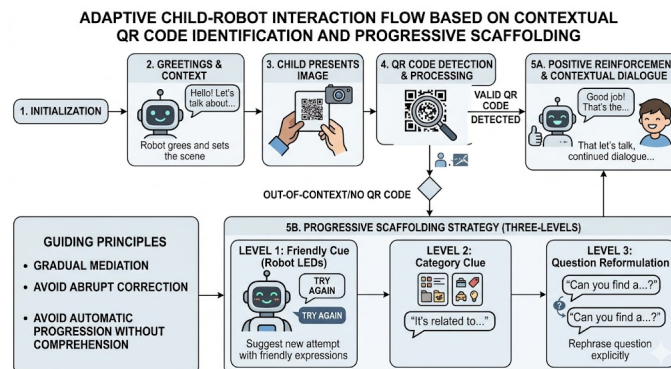


Figure 2. Child-Robot Interaction flow.

3.2.2. Digital auxiliary board system

For participant ID 3, a modular client-server application was developed as an intermediate solution, operated by the researcher to replicate communicative choices in real time and transmit commands to the robot. The architecture comprised three layers: a web-based presentation layer in HTML, CSS, and JavaScript; an application layer using a Python ThreadedHTTPServer bridge with response time under 500ms; and an integration layer translating commands into NAOqi API calls. The interface comprised five screens (Figure 3): home, participant selection, session and activity selection, QR code support, and interaction reports. A movement control panel available on all screens proved pedagogically relevant when participants spontaneously requested unplanned robot movements.

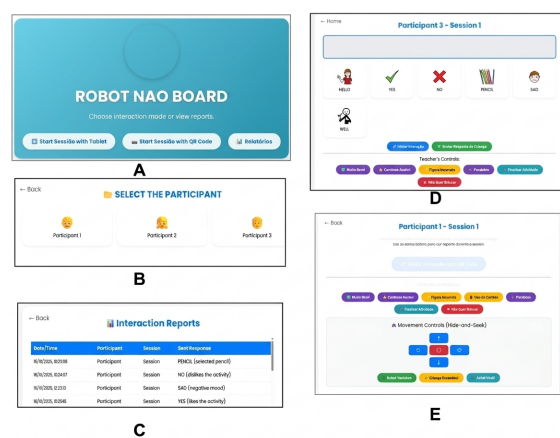


Figure 3. Main screens of the virtual board. A) Interaction mode selection screen; B) Participant selection screen; C) Interaction reports screen; D) Session screen with pictograms; and E) QR code support screen.

3.3. Personalization of interactions and teacher participation

Prior to the sessions, profile characterization forms were applied with parents, guardians, and MRR teachers, covering preferences, stimuli, communicative routines, and AAC history. This guided robot characterization, pictogram selection, and activity planning. Participant ID 1's affinity for the Kuromi character defined the robot's visual characterization and color palette. For ID 2, whose preferences were volatile, the robot's physical movements served as the primary engagement resource. For ID 3, social games such as playing ball, hide-and-seek, and painting guided the interactions.

3.4. Data collection and analysis

Two structured instruments were applied simultaneously in each session. The SRM Teacher Assessment Form covered the child's behavioral state, engagement and affective reaction, perception of motivation and communication, personalization adequacy, and post-session observations. The Researcher Evaluation Form documented initial reactions, attention to instructions, resource handling, communicative attempts, and post-session reflections. Both instruments used open-ended questions. Data from both forms, combined with video recordings, were analyzed in an integrated manner, guiding iterative adjustments to the system and pedagogical strategies across sessions.

3.5. Application in school context

The systems were applied from October 20th to November 12th, 2025, in ten sessions: four with ID 1, two with ID 2, and four with ID 3. Before each session, a pre-interaction moment established a shared communicative frame between the child, teacher, and robotic system, a condition identified in the literature as central to mediated interactions [Light and McNaughton 2014]. The NAO was positioned on the floor to allow movement flexibility, with participants on a mat at 12 to 15 centimeters for QR code reading (Figure 4). Sessions were planned in advance based on individual stimuli (Section 3.3) and adjusted when necessary, reflecting the iterative character of the DSR approach.



Figure 4. Records of pre-interaction moments. (a) Child, teacher and researcher before the interaction giving instructions for the study and (b) Preparation of the MRR with cameras and the robot positioned in the space dedicated to the interaction.

4. Results and discussion

The results are organized around three axes: acceptance of resources, development of autonomous AAC use, and generalization to natural contexts, analyzed in an integrated manner using video recordings and the two assessment forms applied simultaneously in all sessions.

4.1. Acceptance of resources

All three participants accepted the robot-mediated AAC resources through trajectories shaped by the personalization strategies co-planned with the MRR teachers. Participant ID 1 demonstrated immediate acceptance, recognizing the robot as Kuromi, addressing the NAO by the character's name, and spontaneously searching for the communication album without teacher intervention, consistent with the principle that motivation for AAC use emerges when the resource is embedded in personally relevant contexts [Light and McNaughton 2014]. Participant ID 2 demonstrated progressive acceptance mediated initially by the robot's physical movements rather than communicative content; the turning point occurred when the participant understood that the robot only responded through the AAC resource, a deliberate strategy that created a functional context for use without direct imposition, illustrating how the robot can function as a motivational scaffold rather than a mere technological novelty [Chevalier et al. 2022]. Participant ID 3's acceptance was more gradual, with teacher mediation progressively receding as the participant internalized the communicative logic of the interaction, consistent with gradual release of responsibility in mediated learning models [Feuerstein et al. 2015].

4.2. Development of autonomous AAC use

All three participants demonstrated measurable progress in autonomous AAC use, with trajectories reflecting both individual profiles and the quality of teacher mediation. Participant ID 1 evolved from teacher-prompted to fully spontaneous use, progressively expanding her repertoire of figures, suggesting the beginning of communicative appropriation [Vygotsky 1978]: the resource, initially external and mediated, began to be internalized as a personal communicative instrument. Participant ID 2 progressed across just two sessions from continuously mediated use to independently conducting a complete activity sequence involving a cardboard maze without requiring cues for each communicative attempt. Participant ID 3 demonstrated the most remarkable trajectory: in the first session gestures still preceded board use; by the third, the resource was used continuously to request materials and initiate social interactions; by the fourth, the participant directed the sequence of participation of the teacher, researcher, and robot in a group game, exercising an active and generalized communicative role. This shift from responsive to initiative-taking behavior reflects the development of communicative competence beyond operational skills [Light and McNaughton 2014], consistent with situated learning frameworks that emphasize authentic, socially embedded practice [Lave and Wenger 1991].

4.3. Generalization of communicative competence to natural contexts

The most educationally significant finding was the generalization observed in participant ID 3. After the second session, the regular classroom teacher, who had not participated in the intervention and received no guidance from the research team, spontaneously reported an increase in functional AAC use in the classroom and described adopting a strategy analogous to that employed during the sessions. This constitutes evidence of pedagogical replicability: the mediation model developed in the MRR was assimilated and reproduced by another professional in a different context without explicit instruction. The most significant record was a video provided by the school of participant ID 3's presentation at the Science Fair, in which the participant delivered a complete presentation using the communication board consistently and autonomously, in front of the school community, without the robot's presence. What transferred was not the interaction with the technology, but the communicative disposition and the appropriation of the AAC resource as a personal tool, reinforcing that personalization functions as a pedagogical condition rather than a motivational add-on [Carruthers et al. 2020][Schreibman et al. 2015]. For participants ID 1 and ID 2, informal MRR reports indicated initial signs of transfer, though the short observation period did not allow for equivalent formal documentation.

5. Conclusion, limitations and future work

This paper presented a hybrid architecture that integrates the NAO V6 robot as a pedagogical mediator into pre-existing school AAC practices, addressing both the resistance of students with ASD to functional AAC use and the technical incompatibility between heterogeneous AAC formats and the robotic platform. Preliminary results from ten sessions with three participants suggest feasibility across resource acceptance, development of autonomous AAC use, and generalization to natural contexts.

The central argument reinforced by these results is that the effectiveness of social robotics in inclusive settings does not derive from the device's intrinsic capabilities, but

from the quality of the pedagogical integration in which it is embedded. The teacher's role in co-planning, personalizing, and progressively withdrawing mediation was not a secondary condition but a structural one, with direct implications for the design of future robotic systems for education.

Among the limitations, the most significant are the small sample, the variation in sessions per participant, and the short observation period, which limit generalizability and prevent systematic assessment of skill maintenance.

Cost is another factor to consider regarding scalability: although the QR code system was intentionally designed to be low-cost and modifiable by non-technical teams, the NAO robot itself represents a significant acquisition cost for most public schools; thus, large-scale adoption would likely require lower-cost robotic platforms or resource-sharing models among the MRRs. Teacher training is also a prerequisite for autonomous use of the system beyond this study: while teachers actively participated in collaborative planning, they did not directly operate the technical components, meaning future implementations would require a structured onboarding process to enable MRR teams to independently manage both the QR-coded materials and the auxiliary digital dashboard.

Future work aims to expand the study to a larger and more diverse sample across multiple MRRs, conduct longitudinal investigation of communicative gains, and develop a version of the digital auxiliary board usable directly by students and teachers without researcher support. We also plan to incorporate complementary quantitative metrics — such as response latency, frequency of independent AAC initiations, and rate of generalization across contexts — to strengthen future assessments of intervention impact beyond the qualitative and observational data collected in this study.

Use of Artificial Intelligence

Generative artificial intelligence tools were used in the preparation of this manuscript as writing and revision aids. Specifically, a large language model was employed to support the drafting and refinement of sections of the text, improve clarity and fluency in English, and assist in the structural organization of the manuscript. All content, analyses, interpretations, and conclusions are entirely the responsibility of the authors. The AI tools did not participate in the design of the study, data collection, or data analysis. All AI-generated suggestions were critically reviewed, edited, and validated by the authors before inclusion in the final manuscript.

Acknowledgements

The authors acknowledge the financial support provided by the Financiadora de Estudos e Projetos (Finep), the Ministry of Science, Technology and Innovation (MCTI), and the National Fund for Scientific and Technological Development (FNDCT) under the MCTI/Finep/FNDCT ProInfra Regional Development – North, Northeast and Central-West (NNECO 2024) Public Call, through the subproject “Assistive and Collaborative Technological Solutions to Support Educational Inclusion” (STecACAIE). This support covered the expenses associated with participation in and presentation of this work.

References

- Alnafjan, A., Alghamdi, M., Alhakbani, N., and Al-Ohali, Y. (2024). Improving imitation skills in children with autism spectrum disorder using the nao robot and a human action recognition. *Diagnostics*, 15(1):60.

- APA (2022). *Diagnostic and statistical manual of mental disorders*. American Psychiatric Association Publishing.
- Bartl-Pokorny, K. D., Pykała, M., Uluer, P., Barkana, D. E., Baird, A., Kose, H., Zorcec, T., Robins, B., Schuller, B. W., and Landowska, A. (2021). Robot-based intervention for children with autism spectrum disorder: a systematic literature review. *Ieee Access*, 9:165433–165450.
- Beukelman, D. R., Mirenda, P., et al. (1998). *Augmentative and alternative communication*. Paul H. Brookes Baltimore.
- Bondy, A. S. and Frost, L. A. (1994). The picture exchange communication system. *Focus on autistic behavior*, 9(3):1–19.
- Carruthers, S., Pickles, A., Slonims, V., Howlin, P., and Charman, T. (2020). Beyond intervention into daily life: A systematic review of generalisation following social communication interventions for young children with autism. *Autism Research*, 13(4):506–522.
- Chevalier, P., Ghiglino, D., Floris, F., Priolo, T., and Wykowska, A. (2022). Visual and hearing sensitivity affect robot-based training for children diagnosed with autism spectrum disorder. *Frontiers in Robotics and AI*, 8:748853.
- dos Santos, L. P. and Paradedá, R. B. (2026). Mapping the landscape of robotics for autism spectrum disorder: A scoping review of technologies, applications, and future directions. In de Freitas, R. and Furtado, D., editors, *Intelligent Systems*, pages 291–305, Cham. Springer Nature Switzerland.
- Dresch, A., Lacerda, D. P., and Antunes Jr, J. A. V. (2014). Design science research. In *Design science research: A method for science and technology advancement*, pages 67–102. Springer.
- Feuerstein, R., Feuerstein, R., and Falik, L. H. (2015). *Beyond smarter: Mediated learning and the brain's capacity for change*. Teachers College Press.
- Feuerstein, R., Rand, Y., and Hoffman, M. B. (1981). The dynamic assessment of retarded performers: The learning potential assessment device, theory, instruments and techniques. *International Journal of Rehabilitation Research*, 4(3):465–466.
- Hevner, A. R., March, S. T., Park, J., and Ram, S. (2004). Design science in information systems research1. *MIS quarterly*, 28(1):75–106.
- Lave, J. and Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge University Press, Cambridge.
- Light, J. and McNaughton, D. (2014). Communicative competence for individuals who require augmentative and alternative communication: A new definition for a new era of communication?
- Moraes, J. F., Arrua, M. T. S., and de Fátima Silva, R. (2023). Os desafios do professor na inclusão do aluno com transtorno do espectro autista na escola regular. *Revista Diálogos Interdisciplinares*, 2(12):119–132.
- Nunes, D. and Walter, C. (2020). Aac and autism in brazil: a descriptive review. *International Journal of Disability, Development and Education*, 67(3):263–279.

- NUNES, D. R. d. P., BARBOSA, J. P. d. S., and NUNES, L. R. d. P. (2021). Comunicação alternativa para alunos com autismo na escola: uma revisão da literatura. *Revista Brasileira de Educação Especial*, 27.
- Peffers, K., Tuunanen, T., Rothenberger, M. A., and Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of management information systems*, 24(3):45–77.
- Scassellati, B., Admoni, H., and Matarić, M. (2012). Robots for use in autism research. *Annual review of biomedical engineering*, 14(1):275–294.
- Schreibman, L., Dawson, G., Stahmer, A. C., Landa, R., Rogers, S. J., McGee, G. G., Kasari, C., Ingersoll, B., Kaiser, A. P., Bruinsma, Y., et al. (2015). Naturalistic developmental behavioral interventions: Empirically validated treatments for autism spectrum disorder. *Journal of autism and developmental disorders*, 45(8):2411–2428.
- Vygotsky, L. S. (1978). *Mind in Society: The Development of Higher Psychological Processes*. Harvard University Press, Cambridge, MA.
- Walter, C. C. d. F. (2000). Os efeitos da adaptação do pecs associada ao currículo funcional natural em pessoas com autismo infantil. Dissertação (mestrado em ciências humanas), Universidade Federal de São Carlos, São Carlos.