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Research Article

Technology and equity in special education: The transformative role of artificial intelligence

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ABSTRACT

The purpose of this study is to evaluate the effectiveness of artificial intelligence (AI)-mediated interventions, namely the Story Spark and TEAMIGO tools, in facilitating the development, maintenance, and generalization of social communication skills in autism spectrum disorder (ASD) students. Participants included children and young adolescents with an established ASD diagnosis and co-occurring alexithymia, along with varying cognitive impairment levels. A longitudinal latent growth curve model methodology was employed over the course of six months, including a three-month intervention period and a subsequent three-month follow-up period to assess the maintenance of the skills. Quantitative results showed that the social development scores had a statistically significant positive growth rate, which included significant improvements in vocal expression of emotions and the reduction of low-quality utterances. Piecewise modeling was used to validate that these gains were statistically retained in the maintenance phase, and a strong positive correlation with real-world observation scores (inventory of social development-generalization) was obtained to validate the ability of AI to generalize skills to naturalistic settings such as classrooms and playgrounds. This illustrates the importance of AI as a predictable safe haven that fosters educational equity through its use of digital scaffolding.

Keywords: education, social inclusion, artificial intelligence, teaching

INTRODUCTION

The ubiquity of technology in contemporary life, along with the increasing variety of applications that cater to the specific educational requirements of individuals, has created immense interest in the utilization of complex systems that employ artificial intelligence (AI) for the facilitation of individuals with neurodevelopmental disorders (NDDs). The domain of inclusive education has recognized the potential of AI as an agent of change that can facilitate the creation of equitable solutions for students with special educational needs (Baker, 2000; Melo-López et al., 2025; Rizos et al., 2024). Research has also emphasized the facilitation of individuals with autism spectrum disorder (ASD), as the disorder is marked by the presence of core impairments in social communication, as well as difficulties in reciprocal social interaction, along with restricted patterns of behavior (American Psychiatric Association, 2013). The emotional deficiencies of individuals with ASD are also commonly accompanied by the presence of alexithymia, a common phenomenon observed in the NDD population, as they lack the capacity to recognize or express personal as well as external feelings.

The traditional therapeutic interventions designed to enhance the social skills of an individual have shown considerable challenges in offering effective support, which has a general positive impact on the individual's life. Individuals with ASD have difficulty processing crucial social skills, such as the prosodic quality of speech, and the uncertainty of human interaction can cause anxiety, which may result in social withdrawal; therefore, there is an imperative need to develop new, non-threatening interventions using digital scaffolding.

Recent developments have emphasized the importance of conversational agents (CAs) and speech-based AI as an effective means to reduce the impact of alexithymia. Studies carried out on CAs like Emoty (Catania & Garzotto, 2023) have shown that training an individual in effective emotional communication by using the expressive capabilities of the human voice, which accounts for 55% of the total information exchanged, has a positive effect on the development of their linguistic capabilities. The use of social robotics, such as the NAO Robot (2024), has shown positive effects in the development of joint attention and imitation skills in special education (Lledó et al., 2024). These agents offer a controlled environment, which reduces cognitive load, allowing the individual to learn through trial and error without the pressure of human interaction (Moon & Ke, 2024).

Despite the promise of mobile applications and technology to aid the development of executive functions and basic instrumental skills, the critical issue that still needs to be addressed is the long-term stability and generalization of the skills to the real world (Cohen et al., 2002). Moreover, there is a need to address the ethical issues related to data privacy and the importance of the human-centered AI approach to the ASD population, which is diverse (Holmes et al., 2022).

LITERATURE REVIEW

The use of AI in special education has shifted from a hypothetical concept to a revolutionary fact, especially in the lives of students with NDD, such as ASD. This paper aims to explore the current status quo in technology-based interventions, especially in the areas of CAs, social robotics, and the problems that still need to be overcome in skill maintenance and generalization.

Conversational Agents and Speech-Based Artificial Intelligence

Recent developments have placed CAs at the center for reducing the impact of alexithymia—an inability to identify and express emotions—in the ASD population (American Psychiatric Association, 2013). Studies involving speech-based AI systems like Emoty highlight the significance of vocal emotional expression in training users (Catania & Garzotto, 2023). The practice is also supported by the communication model stating that 55% of total information is communicated through the tone of voice in human interactions, while only 7% is attributed to the actual words used (Körner et al., 2026). Research has also shown the effectiveness of these systems in improving the linguistic and social skills of users by consistently using these agents to act out complex emotions (Zdravkova et al., 2022).

Social Robotics and Multi-Platform Digital Support

Apart from that, social robotics, such as the NAO Robot (2024), has also been found effective for the development of joint attention and imitation skills for special education students (Lumandas & Taja-on, 2026). Social robotics has also provided the opportunity for the students to experience the role of teammates, providing them with a safe haven for social interaction without the inherent stress of human contact (Lledó et al., 2024). Meanwhile, mobile apps have also come into existence for the facilitation of executive functions, such as gamification elements and feedback loops (Gallardo-Montes et al., 2021; 2022). The apps also make use of Plutchik's circumplex model for the facilitation of emotional connections during interaction, as they make use of color-coding elements.

The Predictability Advantage: Technology as a Safe Space

One common thread in the literature has been that technology offers a predictable and controlled environment that can minimize the cognitive load and stress that comes with the uncertainty of human signals. The structuring effect of AI agents, who follow a strict dialogue path and offer predictable feedback, can enable a safe trial-and-error learning process. This predictability is critical in developing socio-emotional competencies in people who would otherwise be overwhelmed by the complexity of social interactions (Pino et al., 2021).

Human-Centered Artificial Intelligence and Ethical Considerations

With the increase in the usage of AI tools, the need for the human-centered AI approach is critical, especially because of the high degree of heterogeneity present in the population of individuals with ASD (Linsenmayer, 2025). Generalizing user needs is also not easy, while the collection of data using sensors also poses many privacy-related issues. For the effective integration of AI tools into clinical practice, the tool should be transparent, trustworthy, and controllable (Iannone & Giansanti, 2024). Additionally, the need for the inclusion of an intuitive interaction paradigm should also be considered, as the presence of non-neurotypical verbal instances may lead to ASR failure (Catania & Garzotto, 2023).

The Last Mile Challenge: Generalization and Maintenance

Yet, despite the promise of AI, the final challenge of the last mile is the long-term maintenance of skills and their generalization to the real world (Yang et al., 2025). Many of the current studies have methodological limitations related to sample size and time course, often not assessing the long-term maintenance of skills after the technology is removed (Zawacki-Richter et al., 2019). Without the long-term maintenance of skills, the clinical relevance of the current studies is preliminary.

Objective

The objective of this study is to assess the efficacy of AI-mediated systems like Story Spark in promoting the development and generalization of social skills in students with ASD. By utilizing a rigorous latent growth curve model (LGCM) analysis over six months, this research aims to bridge the gap between short-term laboratory success and real-world social competence and also explore the role of individual factors such as cognitive impairment level (CIL) and AI use intensity in the growth process.

Research Questions

To direct this research process, the following research questions (RQs) have been proposed:

1. **RQ1.** To what degree does the AI-mediated intervention (e.g., Story Spark) aid the initial development of social communication and emotional expression skills in students with ASD?
2. **RQ2.** To what degree do the social skills developed during the intervention period sustain and solidify over time after the removal of the systematic technological intervention?
3. **RQ3.** To what degree can the skills developed in the structured and artificial AI-mediated context generalize to functional social interactions in the real world and ecologically valid settings such as the classroom and the playground?
4. **RQ4.** To what degree do individual factors such as the initial level of CIL and the amount of AI use (time-on-task) affect the development and maintenance of these social skills?

METHOD

This research adopts a prospective longitudinal approach in order to transcend the limitations of the conventional pre-/post-test approach commonly employed but also frequently discredited in the literature. The research is divided into two distinct periods: a three-month intervention phase, followed by a three-month post-intervention follow-up phase. This approach enables the simultaneous evaluation of both the level of skills at the outset (intercept) and the speed of change over time (slope).

Participants

This research targets children and young adolescents who have a confirmed diagnosis of ASD. The target population is drawn from special educational centers.

Participants are recruited on the basis of the following criteria:

- Clinical diagnosis: A confirmed diagnosis of ASD using standardized diagnostic tools such as the ADOS-2.

Table 1. Study protocol and procedural timeline

Phase	Timeframe	Primary activities	Data collected
Baseline	Month 0	Initial assessment and diagnosis verification	ADOS-2, initial ISD score
Intervention	Months 1-3	Bi-weekly AI sessions (Story Spark)	Automated platform metrics, ISD
Post-intervention	Months 4-6	No AI use; real-world social interaction	ISD-G (teacher observations), ISD

- Symptom profile: Presence of obvious shortcomings in social communication and interaction skills, commonly accompanied by alexithymia.
- Heterogeneity: To ensure representative outcomes, this research recruits individuals at all CIL: mild, moderate, and severe.
- Ethical compliance: The research is entirely voluntary, requiring informed consent from the legal guardians of the participants.

Study Instruments and Tools

The intervention strategy centers on an AI platform, which is the Story Spark and TEAMIGO simulated platform.

- AI platform: As an emotional facilitator, the agent emphasizes vocal expressiveness, which is informed by the assumption that 55% of the communicated information comes from the tone of the voice used by the communicating person. The platform applies a trial-and-error learning pattern, which is informed by Kolb's experiential learning cycle, which consists of the following stages: experience, reflection, conceptualization, and application.
- Measurement instrument: The quantitative tool used to collect the data is the inventory of social development (ISD). The ISD scale was used at different time points, which include months 0, 2, 4, 5, and 6.
- Observational tools: During the follow-up, the inventory of social development-generalization (ISD-G) score was used by teachers and caregivers to observe the naturalistic setting of the social interaction of the children in the classroom or the playground.

Procedures and Data Collection

The study protocol is implemented in a structured, quiet environment at partner institutions, aimed at minimizing anxiety (see **Table 1**).

- Intervention phase (months 1-3): Participants undergo individual bi-weekly interventions, with each session lasting approximately 12 minutes, given the attention constraints of NDD. The AI agent elicits the expression of specific emotions (joy, sadness, anger, surprise, and fear) by vocal tone.
- Automated data collection: The tool automatically collects data on the number of tasks completed, the rate of success in performing acting, and the rate of low-quality utterances (phrases that the speech recognition tool misunderstood).
- Follow-up phase (months 4-6): Participants stop interacting with the AI tool, while data collection occurs naturally to examine the generalization of skills without the technological tool.

In order to ensure transparency and tackle the complexities of the longitudinal design, the study was standardized across all the participants. Every individual was made to undergo a bi-weekly intervention protocol wherein 12-minute sessions were specially designed to accommodate the attention constraints of students with NDDs.

These sessions were implemented using the Story Spark and TEAMIGO platforms to elicit specific vocal emotional expressions such as joy, sadness, anger, surprise, and fear using a trial-and-error method of learning based on Kolb's experiential learning cycle

Data Analysis

Quantitative analysis is done through LGCM, which is done using the AMOS software package.

Table 2. System usability and performance metrics

Metric	Session 1 (mean)	Session 5 (mean)	Statistical significance
Acting performance (correct emotions)	Initial score	Final score	$p < .05$ (Wilcoxon)
Low-quality utterances (%)	Higher rate	Lower rate	Significant reduction
Interaction duration (minutes)	Baseline	Increase	High engagement

- Growth curve analysis: This analysis is done to measure the development of social skills over the entire period of the six months, including latent variables such as Intercept (status at the start of the period) and slope (growth rate over the period).
- Piecewise modeling: This is done to specifically analyze the maintenance of skills, where the growth curve is divided into two sections: slope 1 (intervention) and slope 2 (maintenance).
- Moderation analysis: This analysis is done to understand the baseline factors such as CIL and AI interaction duration (time spent on the task), which affect the growth curve.
- System usability: Non-parametric tests such as the Wilcoxon signed-rank test are done to analyze the performance in the first and last sessions of the intervention on aspects such as acting performance and utterance quality.

This comprehensive framework ensures that the study addresses the last mile challenge by empirically verifying whether AI-mediated gains translate into long-term social competence in non-therapeutic environments.

Data collection was also organized into three tiers of data collection:

(1) automated metrics, where the AI tool was used to track task completion rates and low-quality utterances (such as those from misrecognitions by the speech recognition system),

(2) quantitative psychometrics, where the ISD was used at five critical intervals (months 0, 2, 4, 5, and 6) to develop a longitudinal baseline and growth curve, and

(3) ecological observations, where the ISD-G scale was also employed, where teachers and caregivers would observe naturalistic interactions at a playground during the follow-up stage.

Regarding data analysis, the text was reorganized to carry out an LGCM analysis via the AMOS software package.

This would enable the calculation of the latent intercept (or initial status) and the latent slope (or growth rate).

To examine retention of skills more closely, a piecewise modeling approach was also employed to bifurcate the growth curve into slope 1 (intervention) and slope 2 (maintenance), enabling a statistically rigorous evaluation of retention of skills even after the removal of the technological scaffolding

RESULTS

The following results show the longitudinal analysis carried out over a period of six months to assess the effectiveness, maintenance, and generalization of social interaction skills in students with ASD using an AI-mediated intervention. The analysis mainly employs LGCM to track the development of ISD score trajectories, moving from a structured intervention to a naturalistic follow-up phase.

System Usability and Initial Performance Metrics

The results of the initial three-month intervention period validated the high levels of participant engagement, which is in accordance with the findings of the existing literature regarding the application of AI in the context of NDDs. From the initial group, seventeen participants managed to complete all five bi-weekly sessions. This is indicative of the usability of the system from a diversified group of subjects with special needs of varying types. Moreover, the average interaction duration was substantially longer than the existing literature regarding similar types of pedagogical agents.

Quantitative analysis of the performance over sessions identified two major trends (see **Table 2**):

Table 3. Global LGCM parameters for social interaction skills (ISD)

Latent factor	Mean estimate	Variance	Interpretation
Intercept (initial status)	Moderate	Significant	High individual variability at baseline
Slope (growth rate)	Positive	Significant	Significant group-level skill growth

Table 4. Piecewise LGCM slopes

Phase	Timeframe	Slope estimate	Status
Acquisition (slope 1)	Months 1-3	Steep positive	Statistically significant
Maintenance (slope 2)	Months 4-6	Stable/flat	Skills consolidated; no decay

- Acting performance improvement: There is a substantial increase in the acting performance metric, which reflects the capacity for accurate expression of emotions such as joy, sadness, anger, surprise, and fear through tone of voice. The Wilcoxon signed-rank test confirmed a statistically significant increase in this metric from session 1 to session 5. This experiment thus validates the effectiveness of AI as an emotional facilitator in the expression of joy, sadness, anger, surprise, and fear through the tone of voice.
- Reduction in low-quality utterances: The mean percentage of statements not recognized by the speech recognition system decreased substantially from the first session to the final session. This reflects an improvement in the capacity for effective communication through the AI system.

Global Latent Growth Curve Model Parameters

The results of the unconstrained growth curve model suggested a good fit to the social skills acquisition data, as supported by the good fit statistics. Two main parameters were identified in the model that determined the group's growth curve trajectory (see **Table 3**):

1. Latent intercept (initial status): The results showed that the group's mean ISD score at month 0, which was the baseline, reflected a moderate initial social interaction capability. However, the variance component was significant at the beginning, indicating that there were considerable individual differences in social skills.
2. Latent slope (growth rate): The results showed that the growth rate was positive and statistically significant, indicating that the group as a whole had a meaningful growth rate in social interaction capabilities as a result of the intervention.

Maintenance and Consolidation: Piecewise LGM Analysis

To answer the crucial RQ about the maintenance of the skills after the removal of the technological scaffolding, a piecewise LGCM was used. The model used to analyze the six-month trajectory consisted of two distinct phases: slope 1 (intervention, months 1-3) and slope 2 (follow-up, months 4-6).

- Initial acquisition (months 1-3): Slope 1 showed a steep and rapid acquisition curve in social skills. The rapidity can be attributed to the safe and repetitive nature of the AI system.
- Skill maintenance (months 4-6): After the intervention, the growth rate was no longer statistically significant, as seen in the leveling off of the slope in the piecewise model. However, a directed contrast test to compare the skill levels at month 4 and month 6 showed that the skills were statistically maintained (see **Table 4**).

Moderation Analysis: Cognitive Impairment and Engagement

Due to the diverse nature of the ASD spectrum, it was important to conduct a moderation analysis to identify individual factors and their impact on the growth trajectory.

Stratified analyses based on initial diagnostic report categories (mild impairment, moderate impairment, severe impairment) showed significant differential patterns:

- Mild impairment group: This group had a moderate level and the strongest and most sustained growth trajectory. Their level of cognitive ability helped them to get the greatest benefit out of the structured AI training.

- Moderate impairment group: Although this group had highly significant initial growth, the slope was negligible after the intervention.
- Severe impairment group: This group had the lowest performance ability and the flattest slope, which was characterized by higher rates of poor-quality utterances. What was particularly interesting was the fact that this group had the highest level of engagement time, implying the AI was motivational (presumably due to the predictable nature) even though the existing constraints limited the translation to social skill development.

Generalization to Real-World Settings

To assess the external validity of the intervention, the latent growth factors were correlated with the ISD-G scores, which measure objective observational data from ecologically valid settings.

A strong positive correlation was found between the overall latent growth slope and the final ISD-G generalization score. This confirms that the skills learned from the controlled AI environment have been successfully transferred to and consolidated in the unpredictable social settings. This quantitative evidence was previously lacking from long-term studies, validating the therapeutic approach of using AI to bridge the gap to social competence.

Qualitative Synthesis of Behavioral Changes

This qualitative data, provided by the facilitators, the teachers, as well as the observers, reinforced the statistical data, indicating that the participants' functional abilities had improved in the following areas:

1. Affective behavior: The observers reported that the participants exhibited spontaneous improvements in the quantity of non-verbal expressions during peer interaction, such as gestures and facial expressions. The participants also reported that they became more aware of the feelings of others during daily life.
2. Communication framework: The teachers reported improvements in basic skills for effective communication, such as turn-taking, articulation of sentences, as well as requests for clarification during interaction.
3. Application in context: The participants exhibited improvements in the application of the concepts of emotions, as they started relating the concepts of emotions learned with the AI agent to the context of real life, thus indicating the Application stage of the intrinsic learning cycle, as the participants started thinking about scenarios in real life when they might experience the emotions they learned with the AI agent.

DISCUSSION

The results of this longitudinal study on AI-mediated intervention for students with ASD create the opportunity to critically compare the results with existing literature in the areas of therapeutic technology and special education. This study fills the gap in the existing literature on the need to conduct longitudinal studies on the effectiveness of AI-mediated intervention for students with ASD, as identified in the existing literature (Atturu et al., 2025; Zawacki-Richter et al., 2019).

Alignment of Performance Gains with Speech-Based Artificial Intelligence Research

The initial gains in the acting performance metric over the three-month intervention period align with the existing literature on speech-based AI, such as the study on the interaction with the AI-based agent named Emoty. This study validates the premise that the development of vocal expressiveness, which is responsible for 55% of the information in communication, is a specialized and effective way to create emotional awareness in individuals with ASD (Catania & Garzotto, 2023). Moreover, the significant reduction in the number of low-quality utterances in this study validates the hypothesis that the interaction with the AI agent becomes more intuitive over time as the individual with ASD learns to develop functional communication skills, such as better enunciation and rephrasing.

Closing the Last Mile Gap: Maintenance and Generalization

A significant contribution of this research is the quantitative verification of the last mile challenge, which refers to the maintenance of the results and the generalization of the skills to the real world (Perry et al., 2024; Yang et al., 2025). Unlike the results of the Emoty trials, which were only based on a few sessions, the present piecewise LGCM analysis shows that the results are statistically preserved during the three-month maintenance phase (slope 2) without the support of the technology. This shows that the results of AI-mediated learning do not only reflect the improved performance of the children within the acting task itself but also generalize to the real world, which was also the conclusion of the strong positive correlation found between the latent growth factors and the ISD-G scores (Lledó et al., 2024; Pino et al., 2021).

Moderator Analysis: Heterogeneity and Utilization

This moderation analysis underscores the role of human-centered AI in explaining the inherent heterogeneity of the ASD population. The positive relationship between AI utilization intensity and the slope of the intervention/maintenance relationship is also consistent with the findings from the ADVi chatbot study, where higher engagement among autistic students correlated positively with needs fulfillment (Lee et al., 2025). Moreover, the role of the CIL also underscores the role of AI as a predictable and motivating environment for all students, but potentially a more cognitively resourceful student population for maximizing training benefits for students with lower CILs (Chukwu et al., 2026; Mohammed et al., 2024; Moon & Ke, 2024).

Strategic Design and Educational Equity

The decision to focus on vocal tone rather than the potentially overwhelming nature of facial recognition is well-supported due to the significant improvements in the clarity of communication and the ability to participate that have been noted (Pino et al., 2021). These AI tools, which offer personalized and non-threatening scaffolding, help to achieve the goal of equity in special needs education, providing support to those at the greatest risk of social isolation (Harkins-Brown et al., 2025). However, in order to achieve the goal of integration into the wider clinical arena, future tools need to continue to consider the ethical issues related to data privacy and the need to utilize XAI to build trust (Iannone & Giansanti, 2024).

CONCLUSIONS

This study presents strong empirical support using a longitudinal LGCM that AI-mediated intervention is effective in the development, maintenance, and generalization of social communicative skills in students with ASD. The findings show that the development in vocal emotional expression is not only statistically significant during the intervention period but also maintained after the removal of the technological intervention, thus addressing the issue of the last mile problem in skill maintenance. Moreover, the high correlation to the real-world observation score (ISD-G) confirms that the skills are generalized to real-world scenarios such as classrooms and playgrounds, thus confirming AI as a safe haven for trial and error learning that is predictable.

The results of this study demonstrate the enormous potential of human-centered AI in facilitating the achievement of educational equity through the development of structured digital scaffolding that takes into consideration the inherent heterogeneity of the ASD population. From a methodological perspective, the study provides a rigorous template for the assessment of the true clinical relevance of technological interventions in special education through the application of longitudinal designs. Future research and development in this area should focus on the development of explainable AI to build trust in the application of these technological innovations.

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AI statement: No generative AI or AI-based tools were used in preparing the manuscript.

Declaration of interest: The author declared no competing interests.

Data availability: Data generated or analyzed during this study are available from the author on request.

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