Sensors and Materials, Vol. 37, No. 11 (2025) 5031–5041
MYU Tokyo

S & M 4230

Artificial Intelligence Technology for Enhancing Learning Outcomes of Children with Disabilities

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(Received March 31, 2025; accepted October 31, 2025)

Keywords: AI-based assistive technologies, special education, cognitive development, language acquisition, engagement levels

We applied artificial intelligence (AI) technology to improve the language learning, communication, and cognitive development of children with disabilities and hearing impairments, and assessed the impact of AI technology on their learning outcomes. Forty-four children were recruited in this study and were randomly assigned to the control and AI-applied groups. Learning progress, engagement level, and overall test score were measured and analyzed. The results showed that insufficient teacher training, a lack of infrastructure, and the absence of tailored educational tools were barriers to AI technology adoption. It is necessary to design customized AI-based educational tools to enhance teachers' professional development and ensure consistent technical assistance. Despite AI technology's advantages in enhancing the learning outcomes in special education, its effectiveness depends on the degree of customization and support to adopt the AI-based tools.

1. Introduction

Artificial intelligence (AI) has significantly advanced educational technology by enabling a wide range of applications.(1) In particular, AI has proven beneficial in special education, supporting children with disabilities in areas such as speech, hearing, and cognitive development.(2) For inclusive education, it is essential that all children, including those with disabilities, have equitable access to AI-based educational tools. AI technologies such as machine learning (ML), natural language processing (NLP), and adaptive learning systems are commonly employed to deliver such educational tools for children with special needs.

Innovations in AI-embedded devices such as speech recognition tools, interactive learning tablet computers, AI-powered hearing aids, eye-tracking systems, gesture recognition systems, emotion-sensing wearables, and robot tutors have facilitated effective learning for children with hearing impairments by enhancing their communication abilities. These devices are utilized for speech recognition training, personalized auditory exercises, and interactive learning experiences.(3) The devices offer real-time feedback, guide learners, monitor progress, and adapt

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https://doi.org/10.18494/SAM5685

ISSN 0914-4935

instructional strategies to meet individual needs. Acoustic sensors for capturing spoken language, vibration sensors for detecting critical sounds, and cameras with motion sensors for tracking hand gestures are collectively used with AI algorithms to suppress background noise and improve the clarity of essential auditory signals. AI-driven speech recognition algorithms further enhance speech comprehension and production.

AI-integrated educational systems rely on big data analytics to monitor student performance and dynamically adjust learning content, thereby increasing engagement and motivation. Previous research results showed that the effectiveness of AI-embedded devices in rehabilitation is contingent upon their ability to deliver immediate, personalized support within adaptive learning frameworks.[4] These frameworks employ gradient descent strategies, which enhance precision and accuracy by minimizing error rates. By leveraging previous learning trajectories and feedback, AI systems can customize instructional content and optimize learning models to better support individual progress.

The role of AI in educating children with disabilities has been extensively studied. AI-enhanced learning environments contribute meaningfully to inclusive education.[5] For instance, Bhardwaj *et al.* highlighted the advantages of AI in personalized speech therapy for children with hearing impairments, noting significant improvements in language acquisition.[6] Additionally, AI-generated learning materials improve the cognitive and motor skills of children with disabilities through engaging and interactive content.[7] In traditional classrooms, AI-integrated educational technologies mitigate challenges by offering accessible materials, individualized support, and immediate feedback.

The development of user-friendly and interactive assistive technologies necessitates the integration of sensors, NLP, and ML. AI-embedded devices and cognitive training programs are designed for those with speech, hearing, cognition, and development challenges. These personalized approaches enable effective rehabilitation programs that are adaptive for individual learners. Therefore, AI plays a pivotal role in enhancing educational outcomes by fostering attention, engagement, and interest in learning.

Despite the benefits of AI in special education, several challenges exist. The availability of AI applications and devices in education is limited. Financial and technological barriers hinder widespread adoption, and educators require proper training to effectively implement AI tools. Although AI-integrated educational devices present positive impacts on general learning outcomes, their long-term effects on children with disabilities must be investigated. Therefore, we explored how the integration of AI technologies into special education improves learning outcomes for children with disabilities. We examined the challenges and opportunities associated with implementation to identify best practices for effective adoption. We also investigated the obstacles faced by educators and administrators, and evaluated the impact of AI on language acquisition, communication skills, and cognitive development, comparing the effectiveness of AI devices used in mainstream schools, special education institutions, and rehabilitation centers.

2. Methodology

We explored AI technology implemented in special education and assessed its effectiveness on learning, particularly the language acquisition, cognitive skills, and communication

development of children with disabilities. We recruited 44 children who were grouped into two: a control group with traditional methods and an AI-applied group with AI-integrated teaching methods. The children were recruited from a special education school, a rehabilitation center, and a general school. They were aged between 5 and 12 years and presented with hearing impairments, and speech and cognitive disabilities. Twenty-two participants were randomly assigned to the control and AI-applied groups. To ensure balanced group composition, an equal number of male and female children belonged to each group. Demographic information, including age, the type of disability, and prior academic performance, was collected to support balanced analysis and interpretation (Tables 1 and 2).

The AI-applied group engaged with AI-based tools such as speech recognition software, cognitive training applications, and interactive learning devices tailored for children with hearing impairments. To compare engagement, communication skills, and cognitive development across groups, we observed and documented the children's interactions with AI technologies during learning activities, and collected educators' feedback.

For data analysis, we employed descriptive statistics, t-tests, and regression analysis to evaluate the impact of AI on educational outcomes. Descriptive statistics were analyzed, and within-group comparisons were conducted using pre- and post-test scores for control and AI-applied groups. Pre- and post-test scores were obtained through observational assessments of learning progress and engagement level by multiple educators before and after intervention, since the participants were children with developmental challenges. To ensure scoring objectivity, data were collected from multiple observers and educators, and outliers were excluded following discussions among the observers or assessing educators. The maximum attainable scores for learning progress and engagement level were set at 30 and 70, respectively, and the maximum total score was 100.

These scores were analyzed using descriptive statistics, t-tests, and regression analysis to determine the effectiveness of AI-based instruction. In the regression analysis, improvement in learning outcomes was selected as the dependent variable, and independent variables included

Table 1
Age of participants in this study.

Gender	Age (years old)								
	5	6	7	8	9	10	11	12	Total
Male	3	2	3	3	3	2	3	3	22
Female	2	3	2	3	3	3	2	4	22
Total	5	5	5	6	6	5	5	7	44

Table 2
Impairment of participants in this study.

Impairment	Age (years old)								
	5	6	7	8	9	10	11	12	Total
Hearing impairment	2	2	2	2	2	2	2	3	16
Speech impairment	1	1	1	2	1	1	1	2	9
Cognitive disability	2	2	2	2	3	2	2	2	17
Total	5	5	5	6	6	5	5	7	44

the extent of AI usage, the level of student engagement, and demographic factors such as age and the type of disability. For the statistical analysis, a significance level of $p = 0.05$ was applied. Data preprocessing was conducted for cleaning and normalization using Python libraries such as Matplotlib, Pandas, and Scikit-learn.

This study was approved by the Institutional Review Board of the Wuhan Yimeng Hearing Rehabilitation Hospital, Wuhan Wuchang District Yimeng Rehabilitation Welfare Institution, and informed consent was obtained from the parents of all the participants. To maintain confidentiality, all data were anonymized throughout the study process. The AI devices used were non-intrusive, age-appropriate, and posed no risk of harm or permanent damage. Ethical guidelines for the responsible use of AI were strictly followed, ensuring that all technologies employed were accessible, safe, and educationally beneficial for the children involved.

3. Impact of AI on Learning Outcomes

To enhance the learning outcomes of students, AI technology has been widely used in special education, especially for children with hearing impairment.[8] AI technology has shown its effectiveness in American English speech therapy to enhance speech skills and general language ability.[9] AI algorithms in speech recognition devices assess speech and optimize teaching content and instruction to effectively correct grammatical and pronunciation errors. One of the related indicators is the improvement in the accuracy of speech, which is calculated as

$$Speech\ accuracy\ improvement\ (\%) = \frac{(posttest\ accuracy - pretest\ accuracy)}{pretest\ accuracy} \times 100. \quad (1)$$

The accuracy improvement is used to measure children's gains by using AI devices in speech therapy. The AI algorithms enable children with hearing impairment to enhance their language skills through immediate and detailed feedback. The AI devices facilitate the construction of a learning environment for the children.

AI devices have proven their capability of aiding children in enhancing cognitive disabilities as they offer personalized cognitive training exercises to improve memory, attention, and executive function.[10] The representative cognitive disability is a neurodevelopmental disorder that shows a prevalence of 9−40% of school children.[10] ML algorithms are used to evaluate children's cognitive skills by gradually increasing the difficulty of tasks for them to solve. AI devices motivate students with cognitive disabilities through personalized learning methods using interactive interfaces and adaptive algorithms. The working memory of the children is increased by AI devices that help them solve difficult tasks progressively. Their progresses are assessed for immediate feedback. Children improve their abilities at their own pace in personalized learning, and consequently, their cognitive potential is enhanced.

The congenital social interaction skills of children with autism spectrum disorder (ASD) were also enhanced by using AI technology. Children with ASD have difficulties in social communication and behavior management. In virtual reality (VR) environments simulating social situations, children can practice eye contact, engage with emotions, and participate in

various activities with peers. As social interactions are essential for children with ASD, repetitive practice is important for them to minimize the stress and unpredictability of social encounters. The individualization and contextualization of the AI-created environment assist them in mastering social skills, enhancing social integration, emotional interpretation, and nonverbal communication.

AI-integrated technologies also considerably assist children with motor disabilities. These children have challenges in physical coordination, fine motor movement, or general movement. Adaptive devices for writing or communication with AI technology assist these children considerably (Fig. 1). For example, eye-tracking devices help children with motor difficulties control devices or communicate using text independently. AI-embedded prosthetics and exoskeletons assist children with motor disabilities by enhancing mobility and enabling participation in previously difficult activities.[11,12] The robot augments the child's motor capabilities and accumulates data to monitor the child's progress over time to ensure successful interventions and meet the child's learning needs.

AI technology is also important in helping children with speech disorders. AI-based speech therapy helps such children improve clarity and fluency in speech, articulation, and communication. The devices for the therapy adopt speech recognition algorithms to analyze a child's speech and provide real-time correction and feedback, enabling the child to practice and refine speaking ability. AI devices can be combined with visual aids to enhance the interactivity of speech exercises and their appeal with animated characters or avatars. Such features effectively help children with speech disorders in related therapy and improve communication skills.

AI technology enables personalized learning, especially for children with cognitive disabilities. Educational platforms with AI are applied to each child's needs through repetitive assessments of improvements to provide customized learning resources.[13] For instance, the content, rate, and manner of learning are adjusted to the child's learning preferences and progress, which is an educational personalization. This helps children with cognitive disabilities

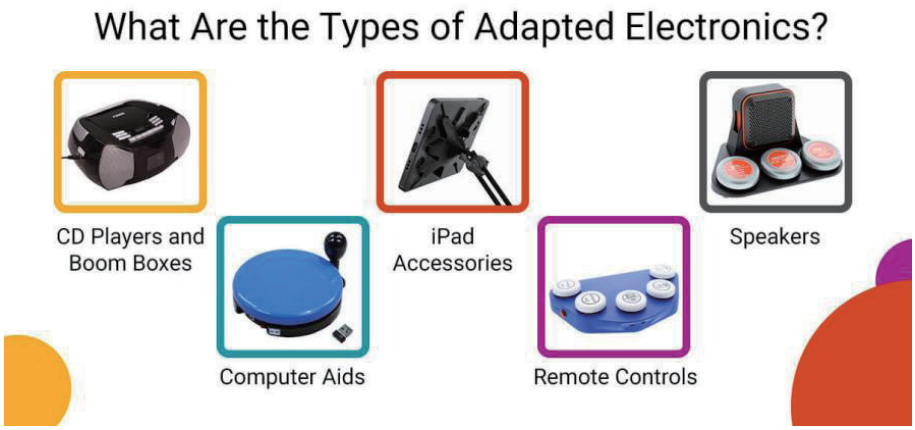

Fig. 1. (Color online) Adaptive devices for children with motor disabilities.

who perform poorly in the standardized educational framework. AI technology addresses learning challenges by offering engaging and optimized learning materials, enabling children to reach their full potential, progress at their own pace, and build confidence in their abilities and skills.

AI technology enables individual interactions in special education and assists teachers and caregivers in supporting children with disabilities appropriately. Educational AI systems help teachers evaluate advancement and provide real-time feedback for children who need more support.[14] The system facilitates the development of educational materials tailored to each child's learning needs to enhance the educational experience. Automated administrative tasks for progress monitoring and reporting allow educators to spend more time on personalized instruction. However, to effectively support children with disabilities with the technology, training educators is mandatory. Through such training, educators can develop teaching strategies and adapt to each child's needs.

However, the effectiveness of AI technology usage relies heavily on how it is implemented in the classroom and customized to each child's ability and requirements. As AI technology is widely used in special education, tailored, flexible, and friendly learning environments for children with disabilities are provided for educational achievement, social inclusion, mental health improvement, and educational equity.

4. Technology in Special Education

4.1 Speech recognition and synthesis

Speech recognition and synthesis technology has been widely used for children with hearing impairment and speech disability. Child's speech is recorded and analyzed to provide real-time feedback on their pronunciation, articulation, and fluency. Such immediacy is critical to help children with speech disability remediation because intervention must be offered as early as possible. The convolutional neural network and long short-term memory are used to process speech and capture important features that are used to correct problems in the speech, and assist educators and therapists in developing appropriate teaching strategies for children. The speech recognition, synthesis, and augmentation abilities of such algorithms allow children to hear the correct pronunciation, intonation, and rhythm of speech, and practice speaking with immediate and tailored feedback in their voices. With AI technology, children are provided with personalized sound training for communication capability enhancement. Tailored speech therapy for children with hearing impairment is provided owing to speech and voice recognition algorithms.

4.2 Adaptive learning

The ML-integrated adaptive learning platform enables children to experience personalized learning tailored to their needs. Performance, learning style, and progress are assessed, and the curriculum, content, and teaching approach are adjusted on the platform. Instructions are

optimized to align with each child's learning pace. The algorithms on the platform provide customized knowledge and pathways for personalized learning using Bayesian knowledge tracing and item response theory. Children's proficiency levels are assessed accurately, and the necessary skills are identified to craft appropriate instructional designs.

4.3 VR and augmented reality (AR) for immersive learning

VR and AR have proven their effectiveness in special education, particularly with children with ASD or sensory processing disability. They help the children practice social interactions, multi-sensory integration, and other cognitive skills. Advanced rendering techniques and physics engines provide various social scenarios in which children can acquire social skills. AR applications enable children to perform quasi-daily activities, increasing task completion rates. As AR and VR environments can be tailored to each child's needs, goals, and learning abilities, their motivation and skill development are enhanced effectively. Interactive learning in VR or environments enhances the cognitive and motor skills of children with disabilities considerably.

4.4 Comparison of AI-integrated and traditional methods in special education

Personalized feedback is beneficial in general education as well as in special education. In the general educational system, children with disabilities have limited access to educational devices and platforms, and are disadvantaged. Therefore, materials and learning devices must be designed and improved for children with disabilities (Table 3).

5. Results

Table 4 reveals that the control group showed enhanced results compared with the AI-applied group for learning progress, engagement level, and overall test score. The learning progress and

Table 3
Comparison of AI-integrated and traditional methods in special education.

Feature	AI-integrated method	Traditional method
Personalization	Highly personalized learning paths; adaptive content and difficulty levels	Standardized curriculum; limited individualization
Feedback	Immediate, real-time feedback; automated error correction and guidance	Delayed feedback; manual correction and guidance
Accessibility	Enhanced accessibility through speech recognition, text-to-speech, and multimodal interfaces	Limited accessibility features; reliance on traditional sensory channels
Engagement	Increased engagement through interactive simulations, gamified learning, and personalized challenges	Varied engagement levels; reliance on traditional lecture and worksheet formats
Collaboration	Enhanced collaboration through AI-mediated communication platforms; AI-driven suggestions for group formation	Limited collaboration; reliance on traditional group activities and teacher mediation
Adaptability	Easily adaptable to various learning styles and disabilities; continuous improvement through machine learning	Less adaptable to diverse learning needs; limited potential for continuous improvement

Table 4
Scores of control and AI-applied groups before and after using AI technology in education.

Group	Learning progress		Engagement level		Overall test score	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Control	20.59	26.18	45.64	59.32	7.55	8.55
AI-applied	18.36	22.55	45.27	58.68	7.50	8.50

engagement of the control group were more pronounced than those of the AI-applied group, demonstrating improvement with AI integration. Higher AI technology's effectiveness was observed more in the control group than in the AI-applied group, although both groups showed the effect of AI technology usage in education.

The regression model was established to examine the relationships among AI technology usage, learning progress, engagement level, and overall test score. Before using AI technology, a moderate correlation between learning progress, engagement level, and AI technology usage was observed with an R of 0.461. The two variables accounted for 46.1% of the total variance. Four in ten children were keen on using AI technology and fully committed customers. After using AI technology, the correlation between learning progress, engagement level, and overall test score became weaker with an R of 0.446, which slightly decreased from the value obtained before using AI technology (Table 5).

6. Discussion

6.1 Challenges of using AI technology in special education

Challenges are found in using AI technology in special education. The first challenge is the lack and inadequacy of training programs for educators. Most of them do not have expertise in using AI technology.[13] This is more pronounced in special education than in general education because the devices must be designed for children with disabilities. Educators must understand the functionality of AI technology and devices to tailor them to children with various needs. AI technology can be underutilized when educators do not understand and utilize it appropriately. The lack of technological networks and systems across schools and companies is another challenge to tackle. Schools providing special education might not be included in the educational network in which AI technology is provided and trained. Most schools for special education have a deficiency of technology, equipment, broadband access, and technical assistance due to budget constraints. The effective application of AI technology requires stable procurement, reliable Internet access, swift data exchange, and immediate data processing.[15]

Despite the large potential to enhance special education with AI technology, such deficiency constraints impact educational activities in special education schools. It is necessary to invest more in purchasing devices and software, as the lack of necessary infrastructure worsens the situation and hinders schools for special education from maintaining or integrating AI technology in their educational systems.

In AI technology usage, ethical issues must be considered. Data privacy and security are essential as the personal data of children must be protected by preventing data exploitation,

Table 5
Regression models of scores of pre- and post-tests.

Model	R	R^2	Adjusted R^2	Standard error of estimate
Pre-test	0.461	0.212	0.174	2.142
Post-test	0.446	0.198	0.159	3.326

phishing scams, and other privacy violations.[16] Educators and administrators need to be allowed to choose appropriate AI devices to tailor to their children. Children with disabilities need to use the necessary devices freely without any discrimination. The adoption of such devices must not reinforce existing biases. All AI devices in a school must be accessible to every child who wants to use them, but such usage must be managed within ethical boundaries.

Special education with AI technology provides great opportunities for children with disabilities. However, the effective usage of AI technology requires appropriate infrastructure, investment, customization, the adequate training of educators, and solving ethical issues. The collaboration of educators, school leaders, policymakers, technology developers, and other stakeholders is essential to encourage the integration of AI technology into special education.

6.2 Effectiveness of AI technology

The effectiveness of AI technology on communication, language, and cognitive skill enhancement was proven for children with disabilities in this study. The results illustrated the significant improvements in the learning progress, engagement level, and overall test score of the control and AI-applied groups, while the control group showed more improvements than the AI-applied group. The control group significantly improved language acquisition in particular, which was confirmed by the regression model. The model also indicated increased data variability. While AI improved the learning progress and engagement of children with disabilities in general, further research is necessary to validate the AI technology's effective personalized assistance for children with disabilities. Individual needs and the complexities associated with measuring learning outcomes in children with disabilities must also be considered to verify the results of this study.

The control group demonstrated higher levels of learning progress and engagement than the AI-applied group. To enhance the effects of AI technology in special education, the methods used in general schools, such as peer tutoring, need to be introduced in special education with AI technology usage. However, the improvements in learning progress and engagement level without AI technology usage were less prominent than with it, which supported further introduction of AI technology in general education for children with disabilities. As personalized learning is enabled by AI technology, it is necessary to tailor special education to each child's needs and capabilities. Active educator involvement and adequate infrastructure are also required to implement AI technology and diverse teaching strategies based on it.

7. Conclusions

AI technology in special education offers abundant opportunities for children with disabilities, but with challenges. AI technology usage improves the language, communication, and cognitive skills of children with disabilities, but nontechnological factors such as educational support, existing infrastructure, and the availability of AI devices must be considered to benefit children with disabilities in special education. It is necessary to leverage AI technology to provide tailored instruction, increase engagement in learning, and enhance the learning outcomes of children with disabilities. Despite the potential of AI technology that fosters language acquisition, communication, and cognitive skills of children with disabilities, methods introduced in general schools need to be integrated with the teaching methods using AI technology. Such integrated teaching methods need to be studied to enhance the learning outcomes of children in special education. AI's role in special education is clear, but it is still necessary to develop the method of customization and personalization of AI-technology-integrated teaching strategies for each child. To maximize the effectiveness of AI usage in special education, adequate training programs for educators, appropriate infrastructure, and decent investment are essential. The effectiveness and challenges in integrating AI technology clarified in this study provide a reference and basis for further studies and policy-making related to special education for children with disabilities.

Acknowledgments

This study was supported by the General Project in Hubei Province Education Science Plan "2023GB126 - Research on the Strategy and Quality and Efficiency Improvement of Collaborative Education and Integrated Development of 'Four-dimensional Community' for Exceptional Children in the New Era", the "Major Project of Philosophy and Social Science Research in Hubei Higher Education Institutions in 2022 (Advanced Funding Project of Provincial Social Science Fund), Project No. 22ZD151", and the "Research on the Implementation Path of Digital Construction for Rural Cultural Industry in Hubei Province".

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