GEORGE BROWN PRESS
JOURNALS, BOOKS & PROCEEDINGS

Journal of Education, Humanities, and Social Research

Review

From Neural Signatures to Classroom Strategies: A Theoretical Model for Educational Intervention in Children with Autism Spectrum Disorder Based on Neuroimaging

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Abstract: Current educational intervention measures often lack a direct connection to the underlying neural mechanisms of ASD. To address this issue, the research, building upon the team's Connectome Computation System (CCS), critically synthesizes existing literature on ASD neurobiology and evidence-based educational strategies to construct a three-tier "neuro-educational" transformation framework. This theoretical model links the neural signatures identified by CCS with the cognitive-behavioral profiles of children with autism, thereby deriving targeted educational principles and actionable classroom strategies. The conclusion asserts that this structured model provides a crucial, scientifically-grounded pathway for translating individual neurocognitive assessments into personalized educational interventions, thereby enhancing the precision, efficacy, and theoretical coherence of support measures for children with ASD in classroom settings.

Keywords: autism spectrum disorder; neuroimaging; educational intervention; neuroeducation

Received: 05 November 2025
Revised: 20 November 2025
Accepted: 23 December 2025
Published: 24 December 2025

1. Introduction

With the annual increase in diagnosis rates, educational intervention for children with autism has increasingly become a shared focus in the fields of education, psychology, and medicine [1-3]. In recent years, the rapid development of neuroimaging technology has provided a crucial window into revealing the intrinsic neural characteristics of autism. Research by scholars such as Wei Yu indicates that individuals with ASD exhibit specific alterations in brain structure, functional connectivity, and white matter integrity [4]. These "neural signatures" provide a biological basis for understanding the behavioral manifestations of autism and establish a scientific foundation for developing more targeted intervention strategies. However, a significant gap remains between current neuroscientific findings and educational practice: educators often struggle to translate neuroimaging assessment reports into concrete, actionable classroom strategies. This "neuro-educational" translation gap limits the scientific rigor and effectiveness of interventions.

Therefore, constructing a theoretical translation model that systematically connects "neural signatures" with "educational strategies" has become a critical issue urgently needing resolution in the field of autism educational intervention. By systematically identifying neuroimaging indicators in children with autism and translating them step-by-step into cognitive-behavioral functional interpretations and educational principles, a scientific, structured, and generalizable "neuro-educational" translation pathway can be established. This will ultimately form an evidence-based educational strategy system tailored to classroom realities, enhancing the effectiveness of educational interventions and the social adaptive capacity of children with autism.

Subsequent sections of this paper will systematically elaborate on the construction of this theoretical model, the interpretation of its connotation, its implementation pathways, and its specific application in educational settings. The aim is to provide a new theoretical and practical paradigm for the educational intervention of children with autism, one that integrates perspectives from neuroscience and pedagogy.

2. Definition

2.1. Autism

Autism, or autistic disorder, is a severe and pervasive developmental disorder. Its core clinical features were first systematically described by Leo Kanner. He characterized the syndrome as being marked by a profound failure to develop interpersonal relatedness, significant language disturbances, and an obsessive insistence on the preservation of sameness, with the onset of symptoms necessarily occurring prior to 30 months of age [5]. With advances in neuroscience, the understanding of autism has deepened from behavioral observation to the level of brain mechanisms. Bauman and Kemper noted that research findings indicate brain abnormalities in individuals with autism are widely distributed across multiple brain regions and neural circuits, including the cerebellar, limbic, and neocortical systems [6]. These diffuse neuroanatomical observations support the conceptualization of autism as a diffuse developmental disorder of the central nervous system rather than a focal pathology. Furthermore, they proposed that this pattern of abnormalities likely stems from disruptions in early neurodevelopmental processes-such as neuronal migration, differentiation, and synaptic pruning-occurring during the first and second trimesters of gestation.

2.2. Neuroimaging

Neuroimaging is an interdisciplinary field that primarily utilizes non-invasive imaging technologies to observe and assess the structure, function, metabolism, and even molecular levels of the central nervous system. Its scope extends far beyond traditional anatomical imaging, broadly encompassing multimodal technological systems such as functional imaging, metabolic imaging, and molecular imaging [7]. Within this field, functional magnetic resonance imaging (fMRI) is currently the most core and mainstream research tool for investigating higher-order human brain functions. Furthermore, other key technologies include structural MRI (sMRI) for observing macroscopic brain architecture, diffusion tensor imaging (DTI) for delineating white matter fiber pathways, positron emission tomography (PET) for reflecting cerebral metabolic states, and electroencephalography/magnetoencephalography (EEG/MEG) with high temporal resolution [8]. Based on the signal acquisition method, these techniques can be categorized into two major classes: non-invasive and invasive. Non-invasive methods form the cornerstone of the field and mainly include fMRI, EEG/MEG, and near-infrared spectroscopy (NIRS). Invasive methods, such as direct recording of neuronal spike signals or electrocorticography (ECoG), are primarily employed in specific clinical or specialized research scenarios [9]. Together, these technologies constitute a multidimensional brain observation system spanning from macro to micro scales and from structure to dynamic function.

2.3. Educational Intervention

To prevent confusion arising from the same terminology, the term "educational intervention" discussed in this paper is strictly confined to its core connotation within the special education perspective. In academic discourse within this field, this term has been defined from multiple angles. Calderwood proposes that intervention generally refers to an intentional intervention in a challenging situation to make a positive difference; specifically regarding educational intervention, it can be defined as actions taken by school personnel to address an area where a student is struggling in order to make progress in their age-appropriate school curriculum [10]. Lestrud further clarifies the scope of intervention, stating that educational interventions should provide students with the support needed to acquire the skills being taught by the educational system and should address functional skills, academic, cognitive, behavioral, and social skills that directly affect the child's ability to access an education [11]. Heward offers a more structural definition, emphasizing that special education itself is a purposeful, systematic intervention process aimed at preventing, remedying, or compensating for students' learning difficulties to promote their full participation in learning and life. Its core framework encompasses three basic types: preventive intervention, remedial interventions intervention, and compensatory intervention [12]. Synthesizing the above perspectives, this paper defines the core connotation of "educational intervention" as: In special education, it is a purposeful, planned system of educational actions based on assessment. It aims, through systematic pathways of prevention, remediation, and compensation, to provide professional support covering multiple skill domains targeted at students' developmental disorders or learning difficulties, thereby promoting their effective participation in learning and personal development.

3. Literature Review and Critical Analysis

This section systematically reviews the neurobiological foundations of Autism Spectrum Disorder (ASD) and critically examines the limitations of prevailing educational intervention models, thereby establishing the necessity for a neuroscience-informed pedagogical framework.

3.1. Neurobiological Foundations of Autism Spectrum Disorder

Neuroimaging research has consistently identified atypical neural architecture and functional connectivity in individuals with ASD, providing a biological basis for their behavioral phenotypes. Structural Magnetic Resonance Imaging (sMRI) studies reveal deviations such as increased amygdala volume and abnormal development of the corpus callosum, which are associated with emotional regulation and inter-hemispheric communication deficits, respectively [13]. Functional MRI (fMRI) investigations further highlight disrupted connectivity within the "social brain" network-encompassing the medial prefrontal cortex, posterior superior temporal sulcus, and amygdala-which underpins impairments in social cognition, joint attention, and theory of mind [14]. Additionally, Diffusion Tensor Imaging (DTI) indicates altered white matter integrity, particularly in tracts facilitating long-range communication, contributing to information integration difficulties [15]. These convergent findings underscore ASD as a condition of "neural dysconnectivity," where localized overgrowth or under-connectivity in specific circuits manifests as the core symptoms of social-communication challenges and restricted/repetitive behaviors. Collectively, these neurobiological discoveries provide the critical theoretical foundation for our research, which seeks to translate specific neural signatures into actionable educational insights.

3.2. Limitations of Current Educational Intervention Models

The mainstream educational intervention models primarily include the following: ASD, Applied Behavior Analysis (ABA), Structured Teaching (TEACCH), The Relationship Development Intervention (RDI). Dominant educational intervention approaches for ASD, while empirically supported for behavior modification, often operate in isolation from these neurobiological insights [16]. ABA emphasizes the reinforcement of target behaviors and reduction of maladaptive ones through environmental manipulation. TEACCH utilizes visual supports and organized physical spaces to enhance predictability and independence [17]. RDI focuses on building dynamic social competencies through guided interactions. Although these models demonstrate efficacy in improving specific adaptive skills, they are predominantly grounded in behavioral observation and lack a systematic mechanism for incorporating individual neural profiles into intervention planning. This creates a significant "translation gap": educators and therapists receive diagnostic reports indicating neural anomalies (e.g., "reduced prefrontal-amygdala connectivity") but possess no clear, standardized pathway to translate such findings into actionable classroom strategies [18]. Consequently, interventions may not adequately target the underlying neurocognitive dysfunctions, potentially limiting their generalizability and long-term effectiveness. This critique aligns with the identified practical pain point of "disconnection between assessment and educational intervention," as revealed in our project's survey of 2,673 stakeholders.

3.3. Literature Critique: The Behavior-Neuroscience Gap

A critical synthesis of the literature reveals a persistent and significant gap between advancements in the neuroscience of ASD and the practical design of educational interventions. While neuroimaging studies have made substantial progress in delineating the atypical brain structure and function associated with ASD, the predominant intervention models-ABA, TEACCH, RDI, and others-remain fundamentally anchored in modifying observable behavior. They operate on a "top-down" logic, inferring cognitive or neurological deficits from behavioral outputs, rather than a "bottom-up" approach that directly targets identified neural dysfunctions.

This creates a two-fold problem. First, it leads to a lack of explanatory power; interventions may change a behavior without addressing its root neurocognitive cause, potentially limiting the depth and durability of change. Second, it results in a lack of precise targeting; without a direct link to neural mechanisms, interventions cannot be truly individualized or optimized based on a child's specific neurobiological profile. For example, a child with pronounced amygdala hyperactivity (a neural signature for threat hypersensitivity) and a child with reduced prefrontal-amygdala connectivity (a signature for emotion regulation difficulty) might both exhibit "tantrums," but the optimal intervention strategy for each likely differs. Current models lack the granularity to make this distinction, often applying similar behavioral strategies to superficially similar behaviors. Therefore, there is an urgent need for intervention frameworks that explicitly bridge this divide, using neuroscientific evidence not just for explanation, but for the principled design and personalization of educational strategies. This critique directly aligns with and motivates the core objective of our proposed "From Neural Signatures to Classroom Strategies" theoretical model.

4. Core Dilemmas in Intervention

4.1. Disconnection between Mechanisms and Methods

Current intervention strategies face dual challenges: ambiguous target identification and misalignment with neurofunctional remodeling objectives. Autism Spectrum Disorder (ASD) is fundamentally characterized by neural connectivity impairments in the "social brain" network, including disrupted connectivity and white matter integrity. However, existing interventions predominantly focus on superficial behavioral adaptations like generalized social imitation and surface-level etiquette training, failing to precisely address these core neurodevelopmental deficits [19]. Although early behavioral interventions have demonstrated neuroplasticity effects, many approaches still neglect targeted goals such as "functional brain zoning development" and "neural connectivity optimization." This misalignment creates a disconnect between lab-based interventions and real-world social contexts, preventing fundamental improvements in autistic children's brain development. Ultimately, such approaches become disconnected from the core objectives of neurofunctional remodeling.

4.2. Disconnection between Assessment and Stratification

At the intervention design level, the core issue lies in the absence of a stratification mechanism for educational interventions. Children with ASD exhibit significant individual heterogeneity in neurodevelopmental characteristics, which directly determines their cognitive load, skill acquisition pace, and types of support needs in learning scenarios. However, existing intervention programs generally lack scientific and precise stratification criteria, relying predominantly on behavioral scales or clinical experience, failing to provide differentiated support tailored to children's neurodevelopmental differences [20]. For instance, Zhou Nianli's research indicates that even at the same behavioral performance level, ASD children with different neurodevelopmental backgrounds show significant differences in adaptability to teaching pace, support intensity, and intervention methods [21]. Direct application of uniform intervention protocols may result in some children struggling to benefit due to insufficient support or excessive intervention. The root cause lies in the education field's lack of an effective "translation" framework and quantifiable standards that effectively link objective neuroimaging indicators with educational support levels. This renders personalized interventions mere slogans, making it difficult to achieve genuine neurodevelopmental needs-oriented approaches.

4.3. Disconnection between Scenarios and Systems

Intervention scenarios suffer from fragmentation, lacking cross-scenario coordination and consistency. The remodeling of neural functions requires sustained and coherent environmental stimulation support. However, current interventions are mostly confined to single scenarios such as school classrooms or home training, lacking cross-scenario collaborative mechanisms among families, schools, and communities. On one hand, interveners from different scenarios-teachers, parents, therapists-lack unified neurocognitive assessment criteria, leading to inconsistent intervention goals and methods. On the other hand, skills acquired by ASD children in classrooms, such as structured task execution and multimodal communication, are difficult to generalize due to the lack of corresponding support strategies in family environments, and vice versa. This scenario fragmentation results in insufficient coherence of neural stimulation, which not only violates the core goal of "early integration" but also weakens the induced effects of interventions on neural plasticity, thereby limiting the sustained development of social brain functions [22].

4.4. Disconnection between Outcomes and Feedback

In terms of outcome evaluation, there exists a mismatch in assessment metrics that fails to capture neural-level progress. The evaluation of intervention effects has long relied on behavioral observations or standardized test scores, which exhibit slow and insufficient sensitivity in detecting changes. Consequently, these metrics cannot promptly reflect early, microscopic neural plasticity alterations, such as alterations in activation patterns of specific brain regions, potentially leading to delayed instructional adjustments. The core issue of this dilemma lies in the absence of feasible and reliable "proxy indicators" in the education field to indirectly assess neural-level progress, rendering the intervention process a "black box" state and hindering the establishment of a precise feedback loop of "evaluation-intervention-re-evaluation."

5. The Cnstruction of Theoretical Model

5.1. Phase 1: Objective Neuro-Indicator Assessment

This phase serves as the data-driven starting point of the entire theoretical model. Utilizing CCS (Connectome Computation System) scanning technology, multimodal neuroimaging data of children are acquired, covering dimensions such as brain structure, functional connectivity, dynamic developmental trajectories, and disease biomarkers.

Based on these indicators, a Neurodevelopmental Index (NDI) total score is calculated, achieving the transformation from raw imaging data to quantifiable biological markers. According to NDI score intervals, children are preliminarily categorized into four provisional levels: an NDI ≥ 70 corresponds to the most severe classification (Level 3), indicating widespread neurostructural-functional abnormalities; an NDI of 40-69 signifies a moderate classification (Level 2), suggesting significant deviations in specific networks or brain regions; an NDI of 15-39 represents a mild classification (Level 1), reflecting issues with local functional coordination; and a score below 15 indicates neurodevelopment within the typical range. This phase fully realizes the automation and objectification of the "neuro-indicator identification" layer, providing a solid biological foundation for all subsequent decision-making and ensuring the precise targeting of interventions.

5.2. Phase 2: Behavioral Corroboration and Tier Confirmation

Building upon the preliminary levels generated from objective neural data, this phase introduces the clinical and educational expertise of an interdisciplinary team to complete the translation and calibration from "neural signals" to "behavioral functions." The team, composed of neurologists, clinical psychologists, occupational therapists, and special education teachers, systematically compares the neural deviation maps output by CCS with behavioral anchors of the child in real-world contexts such as classroom learning and social activities. When the neural classification and behavioral observations show high concordance, the preliminary level is formally confirmed as the final support level. If significant discrepancies arise, a manual review mechanism is triggered. The team will then dynamically adjust the classification by comprehensively considering developmental history, environmental factors, and assessment context. This verification process not only validates the data but also represents the practical implementation of the "cognitive-behavioral function interpretation" theoretical layer.

5.3. Phase 3: Personalized Intervention and Implementation

Considering the varying physiological characteristics and individual differences among children, the CCS can generate a detailed, individualized assessment report based on neuroimaging data and precise brain developmental charts. This systematically quantified report accurately evaluates brain health status, identifies potential issues in early child development, and facilitates the creation of a personalized intervention plan. The plan is directly mapped onto classroom practice: Children at Level 3 will receive one-on-one intensive behavioral intervention, a fully structured environment, and training in survival skills. For children at Level 2, a structured small-group teaching approach is employed, focusing on functional academic and social skills. Children at Level 1 receive compensatory strategy support and consultative services within an inclusive environment. This phase marks the translation from theoretical design to educational action, transforming the neurobiological targets identified by the CCS into actionable strategies. It ensures that every step of the intervention is evidence-based and traceable.

5.4. Phase 4: Closed-Loop and Iterative Optimization

Three to twelve months after intervention implementation, children undergo a CCS re-evaluation involving a new scan and recalculation of the NDI score, thereby forming a dynamic "assessment-intervention-reassessment" closed loop. By longitudinally comparing changes in neural indicators such as the percentage improvement in developmental rate and functional connectivity strength, the team can objectively assess the neuroplastic effects induced by the intervention measures and determine whether brain development is catching up to the normative trajectory. If the NDI decreases by ≥10 points and the developmental rate normalizes, it indicates the current support is effective, and consideration can be given to downgrading the support level or reducing its intensity. Conversely, if neural indicators deteriorate or show no improvement, it triggers a plan adjustment, leading to an upgrade in the support level or a shift to an intensified intervention model. This closed-loop system enables the continuous optimization of intervention strategies based on the dynamic changes in neurodevelopment, truly realizing brain science-based precise educational intervention and ultimately achieving the goal of "early identification, early intervention, and early integration." The entire framework is shown in Figure 1.

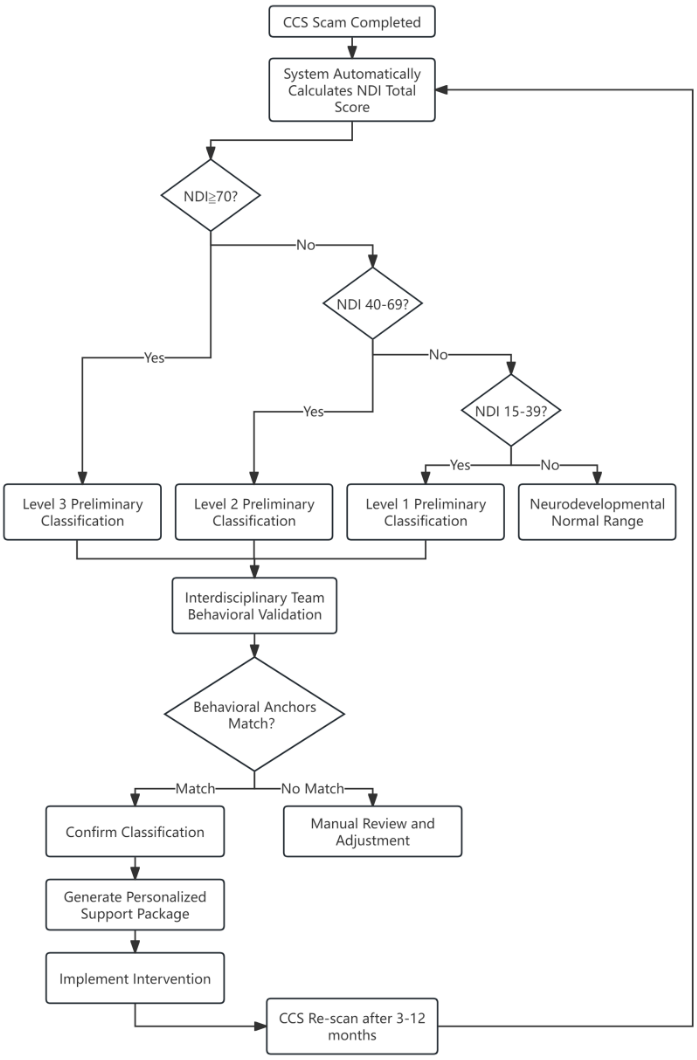

Figure 1. The Framework of Neuro-Education Transformation.

6. Educational Intervention Strategies for Children with Autism Spectrum Disorder

6.1. Designing Sensory-Friendly and Structured Classroom Activities

Autistic children with a higher Neurodevelopmental Index (NDI) may exhibit significant differences in sensory processing capabilities. Kanner proposed that autistic children demonstrate unique sensitivities to sensory stimuli, where both excessive or insufficient sensory input can impact their learning effectiveness [23]. Therefore, classroom activities in settings including autistic children should be designed to be sensory-friendly, avoiding excessive visual or auditory stimulation. For example, in the teaching environment, soft lighting and low-volume background music can be used to create a quiet and comfortable atmosphere. Furthermore, introducing sensory activities, such as tactile exploration tasks, can help children gradually adapt to different sensory stimuli, thereby enhancing their participation and concentration in the classroom.

Simultaneously, structured teaching is a widely recognised method in autism educational intervention [24]. According to this study's transformation theoretical model, the design of structured learning tasks should be tailored for children with different NDI levels. For children with higher NDI, learning tasks should be broken down into smaller, more specific steps, supported by visual aids (such as pictures, flowcharts) to assist comprehension. This structured approach can help children better understand and complete learning tasks, reducing anxiety arising from task complexity. For instance, when teaching mathematical concepts, a complex problem can be decomposed into multiple simple steps, with each step presented graphically, enabling the child to master the concept progressively.

6.2. Adapting the Daily Learning Environment for Autistic Children

According to individualised assessment reports, the learning needs and preferences of each autistic child differ. Research indicates that adjustments to the learning environment can significantly impact a child's learning outcomes [25]. Therefore, classrooms should provide diverse learning spaces to meet the needs of different children. For example, for children requiring a quiet environment, a quiet corner can be established, equipped with comfortable seating and sound-absorbing materials. For children requiring more interaction, a group learning area can be set up, furnished with rich learning materials and interactive tools. Moreover, utilising ROI visualisation technology, teachers can visually understand the neural activity of children in different learning zones, thereby further optimising the layout of learning spaces. Additionally, visual support is a crucial strategy in autism education. In the classroom environment, clear visual cues and schedule boards can be implemented to help children better understand and adapt to the learning environment. For example, using a combination of pictures and text to display the daily learning plan and activity schedule can help children anticipate upcoming events, reducing anxiety. Simultaneously, placing visual prompts in different areas of the classroom, such as reading prompt cards in the reading corner and illustrated game rules in the play area, can help children better understand and participate in various activities.

6.3. Establishing Multimodal and Emotionally Supportive Communication Methods

Regarding communication, autistic children may experience significant challenges, but multimodal communication approaches can effectively enhance their communicative abilities. Consequently, in the classroom, teachers should employ various communication methods, including speech, gestures, pictures, and text. For example, when introducing new concepts, a teacher can concurrently use verbal explanation, gesture demonstration, and picture display to help children better comprehend and accept information. Furthermore, for children with weaker verbal expression skills, augmentative and alternative communication (AAC) tools, such as the Picture Exchange Communication System (PECS), can be introduced to help them better express their needs and thoughts. Concurrently, as emotional support is vital in the education of autistic children. Teachers should encourage children's participation and effort through positive emotional feedback, building an emotional connection with the child. This enables a better understanding of the child's emotional state and allows for timely adjustment of teaching strategies. For instance, when a child completes a task, the teacher can offer positive verbal praise and body language (such as a smile, a nod). Similarly, when a child exhibits anxiety or distress, the teacher can use a gentle tone and comforting body language to alleviate their emotions.

6.4. Promoting Home-School Collaboration and Technology-Enabled Intervention

ROI visualisation technology is one of the core tools of this project, helping teachers understand children's neural activity during the learning process. By regularly using ROI visualisation technology to assess children, teachers can monitor their learning progress and neurodevelopmental changes in real-time. For example, conducting an ROI scan at the beginning and end of a term and comparing the results can clearly show changes in activity within key brain regions. If activity in certain brain regions shows improvement, it suggests the current educational strategies are effective; if activity in some regions shows no significant change or a decline, then educational strategies need adjustment. Building on this, it is also necessary to foster a positive atmosphere at home. Teachers should work closely with parents to jointly develop and adjust individualised intervention plans. Parents can support their child's learning and development by implementing similar educational strategies at home, such as sensory-friendly activities and multimodal communication methods. For example, parents can set up a quiet study corner at home and use a combination of pictures and text to communicate with their child in daily life. Through home-school collaboration, consistent support for the child can be ensured across different environments, thereby enhancing the effectiveness of the educational intervention.

7. Conclusion

Addressing the disconnect between neuroscience research and educational practice in interventions for Autism Spectrum Disorder (ASD), this study, based on connectome computational systems and neuroimaging technology, constructed a four-stage theoretical model. This framework achieves a systematic translation from objective neural signatures to actionable classroom strategies. The research clarified the neurodevelopmental variations in children with ASD, forming four core intervention strategies accordingly: the design of sensory-friendly and structured classroom activities; the establishment of personalised learning environments and visual support systems; the creation of multimodal communication and emotional support mechanisms; and the implementation of interventions through home-school collaboration and ROI technology enablement. This provides educators with scientific and concrete practical guidance. This theoretical model and intervention strategies not only enhance the precision, effectiveness, and theoretical coherence of educational interventions for children with ASD but also promote the empirical application of neuroeducation in the field of special education, offering robust support for improving the neurodevelopment and social adaptive abilities of children with ASD. Future research could further conduct longitudinal studies to explore the long-term effects of interventions on neural plasticity, investigate the adaptability of home-school collaboration models across different cultural contexts, and examine efficient mechanisms for multidisciplinary team collaboration, thereby providing more comprehensive scientific support for educational interventions for children with ASD.

Funding: National Undergraduate Training Program on Innovation and Entrepreneurship (Number:202510345023).

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