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Neuroeducation in Early Childhood Education: A Neuroscience Approach to Optimizing Cognitive Development in Young Children

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ABSTRAK

Early childhood represents a critical period of brain development characterized by high neuroplasticity, during which neural connections rapidly form and are highly responsive to environmental stimulation. Neuroscience research emphasizes that appropriate learning experiences during this "golden period" can significantly influence children's cognitive, emotional, and social development. However, many early childhood education practices still lag behind advances in neuroscience, creating a gap between scientific knowledge about how the brain learns and classroom practices. This study aims to analyze how neuroeducation, as an interdisciplinary approach integrating neuroscience and education, can optimize cognitive development in early childhood education. The research employs a qualitative approach using a systematic literature review of accredited scientific journal articles related to neuroscience, neuroeducation, and early childhood learning. Data were collected from relevant academic publications and analyzed using qualitative content analysis and conceptual synthesis techniques. The findings indicate that neuroeducation-based learning strategies such as play-based learning, music activities, socio-emotional learning, and early numeracy stimulation contribute significantly to strengthening neural connectivity and improving children's executive functions and cognitive abilities. However, the implementation of neuroscience-informed practices remains limited due to insufficient teacher training and the persistence of traditional pedagogical approaches. The study concludes that integrating neuroeducation principles into teacher preparation and curriculum design is essential to effectively utilize the sensitive period of early brain development and support optimal cognitive development in young children.

INTRODUCTION

Early childhood represents one of the most critical periods in human development. Neuroscientific research consistently demonstrates that the early years of life constitute a "golden period" for brain development, during which neural structures develop rapidly and remain highly sensitive to environmental influences. During this

stage, the brain undergoes intensive synaptogenesis, myelination, and neural network formation that shape the foundation for cognitive, emotional, and social functioning throughout life. These processes occur most intensively in the early years, particularly from birth through early childhood, when the brain exhibits high levels of neuroplasticity. Neuroplasticity refers to the brain's capacity to adapt and reorganize neural connections in response to experiences and environmental stimulation. Because of this biological sensitivity, early childhood experiences play a decisive role in determining long-term developmental outcomes. Scientific evidence indicates that the early developmental environment strongly influences the structure and efficiency of neural circuits responsible for learning, memory, attention, and emotional regulation (Vakulenko et al., 2025; Sydnor et al., 2025; Larsen et al., 2023).

The early years of life, particularly from birth to approximately two years of age and extending through the preschool period, represent sensitive windows for the development of key cognitive and behavioral capacities. These sensitive periods are especially important for language acquisition, sensorimotor coordination, emotional development, and executive functions such as attention control, working memory, and cognitive flexibility. Positive developmental experiences during these stages significantly enhance neural connectivity and cognitive efficiency. Activities such as rich cognitive stimulation, warm social interaction with caregivers, physical movement, and musical engagement contribute to strengthening neural pathways associated with learning and emotional regulation. Studies indicate that structured early experiences involving play-based exploration, music exposure, and social interaction promote neural integration and support the development of executive functioning in young children (Tianjiao et al., 2025; Vakulenko et al., 2025; Gea et al., 2025; Cainelli et al., 2025). Consequently, early childhood education plays a crucial role in providing the types of experiences that can optimize neural development and cognitive growth.

However, while the early years provide extraordinary opportunities for positive development, they also represent a period of heightened vulnerability. Adverse experiences during early life may disrupt the delicate balance of neural development and produce long-term developmental consequences. Toxic stress, nutritional deficiencies, environmental deprivation, and exposure to harmful substances during prenatal and early childhood stages can interfere with neural development processes such as synaptic regulation and myelination. These disruptions may alter the timing and quality of sensitive developmental periods and affect cognitive and emotional functioning later in life. Research shows that prolonged exposure to toxic stress can disrupt the balance between excitatory and inhibitory neural processes, which in turn affects learning capacity, emotional regulation, and executive functioning (Margolis & Gabard-Durnam, 2024; Sydnor et al., 2025; Joffe & Robertson, 2025). These findings underscore the importance of creating supportive educational environments that promote healthy brain development during early childhood.

In response to advances in neuroscience, the concept of neuroeducation has emerged as an interdisciplinary field that integrates findings from neuroscience, psychology, and education. Neuroeducation seeks to translate scientific knowledge about how the brain learns into practical strategies for teaching and learning. The central idea of neuroeducation is that educational practices should be aligned with the biological processes underlying learning and cognitive development. By understanding how neural circuits support attention, memory, motivation, and emotional regulation, educators can design learning environments that better support children's developmental needs. In the

`context of early childhood education, neuroeducation emphasizes learning approaches that stimulate curiosity, promote active engagement, and support emotional well-being.

Recent studies indicate that neuroeducation-based strategies have significant potential to enhance early childhood learning outcomes. Systematic reviews show that learning environments incorporating natural exploration, active play, emotional engagement, and intrinsic motivation contribute to improved attention regulation, emotional control, and cognitive performance in young children (Pineda et al., 2025; Chávez et al., 2025; Cabrera et al., 2024). These approaches emphasize experiential learning processes in which children actively explore their environment and construct knowledge through meaningful interactions. Rather than focusing solely on academic instruction, neuroeducation encourages holistic learning experiences that integrate cognitive, emotional, and social development.

In addition to general learning strategies, several specific interventions based on neuroscience have demonstrated positive effects on cognitive development in early childhood. For example, music-based interventions, particularly early exposure to musical training such as piano instruction, have been shown to strengthen neural connectivity related to executive functioning, emotional regulation, and auditory processing. Musical engagement stimulates multiple areas of the brain simultaneously, supporting the development of attention, memory, and emotional expression (Tianjiao et al., 2025; Vakulenko et al., 2025). Similarly, neuroscience-informed approaches to early mathematics education have been found to support the development of numerical cognition and social-emotional skills. Studies indicate that structured mathematical play activities enhance children's understanding of numbers while simultaneously promoting collaborative problem-solving and emotional regulation (Elgavi & Hamo, 2024; Cabrera et al., 2024).

Language development and executive functioning have also been identified as critical domains influenced by neuroeducation-based learning strategies. Neuroscience research highlights the importance of early language exposure and social interaction for the development of neural circuits related to communication and cognitive flexibility. Educational interventions that combine storytelling, interactive dialogue, and problem-solving activities have been shown to enhance linguistic competence and self-regulation among young learners (Khakimova et al., 2025; Cabrera et al., 2024). These findings suggest that integrating neuroscience-informed strategies into early childhood education can significantly enhance multiple domains of child development.

Another important dimension of neuroeducation involves teacher preparation and professional development. Teachers play a crucial role in translating neuroscientific knowledge into classroom practice. However, many educators lack formal training in neuroscience or cognitive development, which may limit their ability to apply brain-based learning principles effectively. Research indicates that professional development programs incorporating neuroscience modules significantly improve teachers' understanding of brain development and increase their readiness to implement brain-based instructional strategies (Ashari, 2024; Muchlisin et al., 2023). These findings highlight the importance of integrating neuroscience education into teacher training programs in order to strengthen the implementation of neuroeducation approaches in early childhood education.

Despite the growing body of research supporting neuroeducation, significant gaps remain between neuroscientific knowledge and educational practice. In many early childhood education contexts, teaching methods still rely heavily on traditional

instructional approaches that may not fully reflect current scientific understanding of how children learn. Studies conducted in Indonesia reveal that while early childhood educators recognize the importance of executive functions for school readiness, their conceptual understanding of these functions remains limited. Moreover, teachers' knowledge of executive functioning does not appear to be strongly associated with years of teaching experience, suggesting that existing teacher education programs may not adequately address this topic (Muchlisin et al., 2023). This gap highlights the need for more systematic integration of neuroscience concepts into teacher training and curriculum development.

Research also indicates that the implementation of holistic early childhood education programs has produced positive outcomes in areas such as socio-emotional development and motor skills, but cognitive development strategies remain insufficiently structured and rarely incorporate explicit neuroscience-based principles. For example, studies on holistic-integrative early childhood education programs demonstrate strong impacts on children's emotional and motor development, yet cognitive learning strategies are often less clearly defined and lack a neuroscience-informed framework (Gea et al., 2025). This suggests that while educational policies increasingly emphasize holistic development, the application of neuroscience-based strategies in cognitive learning remains limited.

Furthermore, emerging educational trends such as STEM education and computational thinking are increasingly recognized as important components of early childhood learning in the twenty-first century. However, the integration of these competencies into early childhood education programs remains relatively weak in many contexts. Teachers often require additional guidance and professional development to effectively integrate STEM learning activities and computational thinking skills into developmentally appropriate classroom practices (Intisari et al., 2024; Yuliantina, 2025). Aligning these educational innovations with neuroscience-informed approaches may help ensure that early childhood education supports both cognitive development and future learning readiness.

At the global level, scholars have also highlighted the persistent gap between neuroscience research and educational practice. One challenge involves the presence of "neuromyths," which are misconceptions about brain function that sometimes influence educational decision-making. These misconceptions may lead educators to adopt ineffective teaching strategies that are not supported by scientific evidence. In addition, communication barriers between neuroscientists and educators often hinder the effective translation of research findings into classroom practice. Researchers emphasize the need for stronger collaboration between neuroscience and education communities in order to develop a shared language and practical frameworks for applying neuroscientific knowledge in educational contexts (Pineda et al., 2025; Khakimova et al., 2025; Elgavi & Hamo, 2024).

Based on these considerations, the novelty of this study lies in its integrative analysis of neuroeducation within the context of early childhood education by synthesizing contemporary neuroscientific findings and educational research. Unlike previous studies that focus primarily on either neuroscience or educational practice, this study attempts to bridge these two domains by examining how neuroscience-informed approaches can be systematically integrated into early childhood education to support cognitive development.

Therefore, the objective of this study is to analyze how neuroeducation approaches based on neuroscientific evidence can be applied to optimize cognitive development in early childhood education while addressing the existing gap between neuroscience research and educational practice in early childhood learning environments.

METHODOLOGY

This study employs a qualitative research approach using a conceptual and systematic literature review design to analyze the application of neuroeducation in early childhood education and its potential role in optimizing children's cognitive development. This approach is considered appropriate because the study aims to synthesize theoretical perspectives and empirical findings from previous research related to neuroscience, early childhood development, and educational practices. The data used in this research consist of secondary data obtained from accredited scientific journals, international publications, and scholarly studies discussing neuroeducation, brain development in early childhood, and neuroscience-based learning strategies. Data collection was conducted through a systematic literature review by identifying relevant publications from reputable academic databases such as Google Scholar, Scopus-indexed journals, and other peer-reviewed sources. The selection of literature was based on several criteria, including relevance to the research topic, publication credibility, and contribution to the discussion of neuroeducation and early childhood cognitive development. Particular attention was given to studies that examine the relationship between neuroscience findings and educational practices in early childhood learning environments.

The data analysis in this study was conducted using qualitative content analysis and conceptual synthesis techniques. First, the collected literature was systematically categorized according to several analytical themes, including the importance of the sensitive period of brain development, the application of neuroeducation in early childhood learning, and the gap between neuroscience research and classroom practices. Each selected study was examined to identify its main arguments, empirical findings, and theoretical contributions related to brain-based learning strategies and cognitive development in early childhood. Subsequently, a comparative analysis was conducted to identify similarities, differences, and emerging patterns across the selected studies. This process enabled the identification of key insights regarding effective neuroeducation practices and the challenges associated with their implementation in early childhood education settings. Finally, a conceptual synthesis was carried out to integrate these findings into a coherent framework explaining how neuroscience-informed educational strategies can support optimal cognitive development in young children. Through this analytical process, the study aims to provide a comprehensive understanding of how neuroeducation can be systematically applied in early childhood education to bridge the gap between neuroscience research and educational practice.

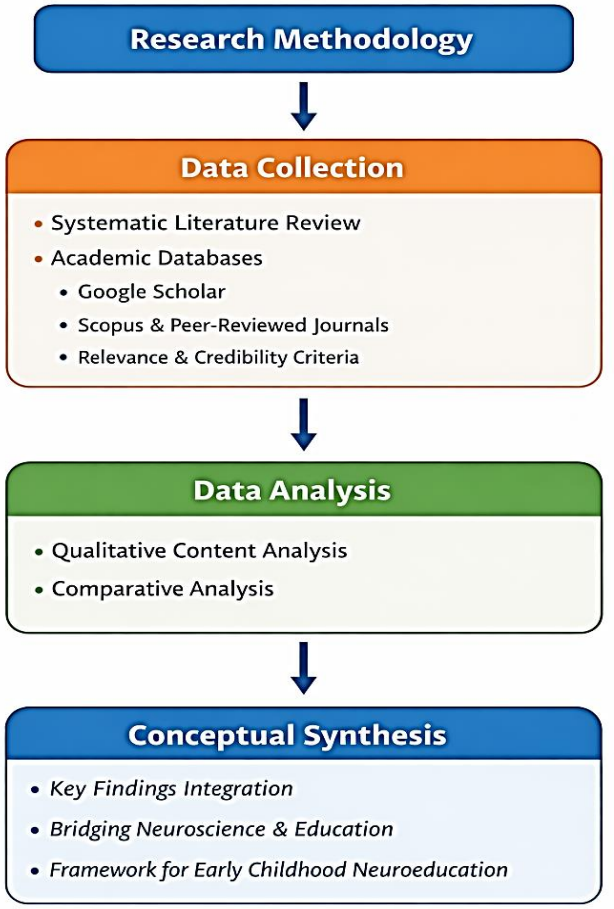

Figure 1. Diagram Conceptual Research

RESULTS AND DISCUSSION

To analyze how neuroeducation approaches contribute to optimizing cognitive development in early childhood education, this study synthesizes findings from various empirical and theoretical studies identified through the systematic literature review process. The analysis focuses on identifying key domains in which neuroscience-informed learning strategies influence early childhood cognitive and socio-emotional development. These domains include cognitive stimulation, emotional regulation, executive function development, and teacher preparedness in implementing brain-based learning strategies. The results of the synthesis are summarized in Table 1, which presents the major neuroeducation domains, their educational applications, the developmental benefits identified in previous studies, and the supporting empirical evidence.

Table 1. Key Domains of Neuroeducation Applications in Early Childhood Education

Neuroeducation Domain	Educational Application	Developmental Benefits	Supporting Studies
Early Brain Stimulation	Multisensory play, exploration-based learning, language-rich interaction	Enhances neural connectivity, cognitive processing, and language	Vakulenko et al. (2025); Sydnor et al. (2025); Larsen et al. (2023)

		acquisition	
Music and Artistic Activities	Early music training, rhythm and piano-based learning	Strengthens executive functions, emotional regulation, and neural integration	Tianjiao et al. (2025); Vakulenko et al. (2025)
Early Mathematics Learning	Play-based numeracy, problem-solving activities	Improves numerical cognition, reasoning ability, and socio-emotional competence	Elgavi & Hamo (2024); Cabrera et al. (2024)
Socio-Emotional Learning	Collaborative play, empathy-based activities, emotional awareness training	Supports emotional regulation, empathy development, and social interaction	Chávez et al. (2025); Joffe & Robertson (2025)
Teacher Professional Development	Neuroscience-based teacher training programs	Increases teachers' understanding of brain development and improves instructional practices	Ashari (2024); Pineda et al. (2025); Muchlisin et al. (2023)

The findings summarized in Table 1 indicate that neuroeducation offers a comprehensive framework for improving early childhood learning by aligning educational practices with the biological processes of brain development. Early cognitive stimulation through play-based and multisensory activities significantly enhances neural connectivity and supports language and cognitive development during the brain's sensitive periods. Activities such as music and artistic engagement stimulate multiple neural systems simultaneously, strengthening executive functions and emotional regulation capacities that are essential for learning readiness.

Furthermore, early mathematics learning integrated with play-based approaches supports both cognitive and socio-emotional development by encouraging problem-solving and collaborative interaction among children. Socio-emotional learning strategies also play a crucial role in helping children regulate emotions and develop empathy, which are important components of healthy brain development. In addition, teacher professional development emerges as a critical factor in the successful implementation of neuroeducation. Teachers who receive neuroscience-informed training demonstrate improved knowledge of brain development and are better equipped to design learning environments that support optimal cognitive growth in young children. Overall, the results suggest that integrating neuroscience principles into early childhood education can significantly enhance the effectiveness of learning environments and help bridge the gap between neuroscience research and educational practice.

Discussion

The findings presented in Table 1 indicate that neuroeducation provides a comprehensive framework for aligning early childhood educational practices with the biological processes of brain development. The synthesis of previous research demonstrates that early childhood represents a critical developmental period in which neural plasticity reaches its peak. During this period, rapid synaptogenesis, myelination, and the formation of complex neural networks occur, making the developing brain highly responsive to environmental stimuli. These processes highlight the importance of providing appropriate cognitive and socio-emotional stimulation during early childhood to support optimal brain development. Neuroscience research consistently shows that the early years of life constitute a sensitive developmental window in which experiences have long-lasting effects on neural architecture and cognitive functioning (Vakulenko et al., 2025; Sydnor et al., 2025; Larsen et al., 2023). The presence of this sensitive developmental period provides strong scientific justification for educational approaches that intentionally stimulate cognitive development during early childhood.

The concept of the "golden period" of brain development reflects the biological reality that neural plasticity is significantly higher in early childhood than in later developmental stages. From birth to approximately two years of age, followed by the preschool period, children experience rapid neural growth that supports the development of language, sensorimotor coordination, emotional processing, and executive functions. These cognitive capacities form the foundation for later academic achievement and socio-emotional competence. Positive developmental experiences during this period significantly strengthen neural connectivity and improve the efficiency of neural networks associated with learning and emotional regulation. Activities such as cognitive stimulation through play, warm and responsive social interactions, physical movement, and musical engagement contribute to strengthening neural pathways involved in attention, memory, and executive functioning (Tianjiao et al., 2025; Vakulenko et al., 2025; Gea et al., 2025; Cainelli et al., 2025). Therefore, early childhood education plays a crucial role in providing enriched learning environments that support optimal brain development.

However, the early developmental period also represents a stage of heightened vulnerability. While positive experiences strengthen neural development, adverse conditions during early childhood may significantly disrupt the formation of neural circuits. Exposure to toxic stress, nutritional deficiencies, environmental deprivation, or harmful substances during prenatal and early childhood stages may alter the developmental trajectory of the brain. Neuroscientific evidence indicates that chronic stress and environmental deprivation can disrupt the balance between excitatory and inhibitory neural processes, which may impair synaptic regulation and myelination. Such disruptions can modify the timing and quality of sensitive developmental periods, thereby affecting cognitive development and emotional regulation in later life stages (Margolis & Gabard-Durnam, 2024; Sydnor et al., 2025; Joffe & Robertson, 2025). These findings emphasize the importance of early educational interventions that not only promote cognitive development but also provide emotionally supportive and stimulating learning environments.

In response to these neuroscientific insights, the field of neuroeducation has emerged as an interdisciplinary approach that integrates knowledge from neuroscience, psychology, and educational science. Neuroeducation aims to translate scientific findings about how the brain learns into practical strategies that can be applied in educational

contexts. The fundamental premise of neuroeducation is that educational practices should be designed in accordance with the biological mechanisms underlying learning and brain development. In early childhood education, this approach emphasizes the importance of active learning experiences, emotional engagement, and intrinsic motivation as key elements in supporting children's cognitive growth. By integrating neuroscientific knowledge into teaching strategies, educators can create learning environments that are more aligned with children's developmental needs.

Empirical studies provide strong evidence that neuroeducation-based strategies can significantly enhance cognitive and socio-emotional outcomes in early childhood. Systematic reviews indicate that learning approaches emphasizing natural exploration, active play, emotional engagement, and intrinsic motivation are associated with improvements in attention regulation, emotional self-control, and cognitive performance among young children (Pineda et al., 2025; Chávez et al., 2025; Cabrera et al., 2024). These findings highlight the importance of experiential learning environments in which children actively interact with their surroundings and construct knowledge through meaningful experiences. Unlike traditional instructional models that emphasize passive information transmission, neuroeducation encourages interactive learning processes that stimulate multiple neural systems simultaneously.

Music-based learning activities represent one of the most well-documented applications of neuroeducation in early childhood education. Neuroscience research shows that musical engagement activates multiple areas of the brain simultaneously, including regions associated with auditory processing, motor coordination, emotional regulation, and executive functioning. Early exposure to musical activities such as rhythm exercises or piano instruction has been shown to strengthen neural connectivity and improve cognitive control processes. Studies indicate that children who participate in early music education demonstrate improvements in executive functioning, emotional regulation, and attentional control (Tianjiao et al., 2025; Vakulenko et al., 2025). These findings illustrate how structured musical experiences can serve as powerful tools for supporting neural development during the sensitive periods of early childhood.

Another important domain in which neuroeducation demonstrates significant benefits is early mathematics learning. Neuroscience-informed approaches to early numeracy education emphasize the use of play-based activities that engage children in problem-solving and exploratory learning processes. Research indicates that interactive mathematical activities can stimulate neural circuits associated with numerical cognition while also promoting social interaction and emotional development. Studies show that children who participate in structured mathematical play demonstrate improved numerical reasoning abilities as well as enhanced socio-emotional competencies such as collaboration and persistence in problem-solving tasks (Elgavi & Hamo, 2024; Cabrera et al., 2024). These findings highlight the potential of neuroscience-informed learning strategies to integrate cognitive and socio-emotional development within early childhood education.

Socio-emotional learning also represents a key component of neuroeducation approaches. Emotional regulation and empathy are essential developmental capacities that support both cognitive functioning and social relationships. Neuroscience research indicates that the neural systems involved in emotional regulation are closely connected with those responsible for attention and executive functioning. As a result, learning environments that support emotional well-being can significantly enhance children's capacity to focus, learn, and interact with others. Studies demonstrate that socio-

emotional learning activities such as collaborative play, emotional awareness training, and empathy-building exercises improve children's emotional regulation and interpersonal skills (Chávez et al., 2025; Joffe & Robertson, 2025). These findings reinforce the importance of integrating socio-emotional learning strategies within neuroeducation frameworks.

Teacher professional development emerges as another critical factor in the successful implementation of neuroeducation in early childhood education. Teachers play a central role in translating neuroscientific knowledge into classroom practice. However, many educators have limited exposure to neuroscience concepts during their professional training. This knowledge gap can hinder the effective application of brain-based learning strategies in educational settings. Research indicates that professional development programs incorporating neuroscience modules significantly improve teachers' understanding of brain development and increase their readiness to implement neuroeducation-based teaching practices (Ashari, 2024; Muchlisin et al., 2023). These programs enable teachers to design learning activities that are better aligned with children's cognitive and emotional developmental needs.

Despite the promising potential of neuroeducation, the analysis also reveals a significant gap between neuroscientific research and educational practice in early childhood education. In many contexts, including Indonesia, early childhood education practices remain largely influenced by traditional pedagogical approaches that may not fully reflect current neuroscientific knowledge. Studies indicate that while early childhood educators recognize the importance of executive functioning for school readiness, their conceptual understanding of executive functions remains limited. Furthermore, research suggests that teachers' understanding of executive functions is not significantly related to years of teaching experience, indicating that professional development opportunities related to neuroscience remain insufficient (Muchlisin et al., 2023). This gap highlights the need for systematic integration of neuroscience-based knowledge within teacher education and training programs.

Research on the implementation of holistic-integrative early childhood education programs also reveals important insights regarding the relationship between educational policy and classroom practice. While these programs have demonstrated positive effects on children's socio-emotional and motor development, cognitive learning strategies often remain less structured and are rarely explicitly grounded in neuroscience-based principles. Studies indicate that although holistic-integrative programs promote comprehensive child development, the application of neuroscience-informed cognitive learning strategies remains limited (Gea et al., 2025). This suggests that further efforts are needed to integrate neuroscientific insights into curriculum design and instructional strategies within early childhood education.

Furthermore, emerging educational innovations such as STEM education and computational thinking have become increasingly relevant in the context of twenty-first-century learning. However, the integration of these competencies into early childhood education remains relatively weak. Many educators report difficulties in designing developmentally appropriate STEM learning activities that align with young children's cognitive capacities. Research indicates that teachers require clearer pedagogical guidance and professional development opportunities in order to effectively integrate STEM learning approaches into early childhood classrooms (Intisari et al., 2024; Yuliantina, 2025). Aligning STEM education with neuroscience-informed learning strategies may help ensure that these innovations support children's cognitive

development rather than introducing inappropriate academic pressures.

At the global level, scholars have also identified a persistent gap between neuroscience research and classroom practice. One of the main challenges involves the widespread presence of "neuromyths," or misconceptions about brain function that influence educational decision-making. These misconceptions may lead educators to adopt teaching strategies that lack scientific support. In addition, communication barriers between neuroscientists and educators often hinder the translation of research findings into practical educational strategies. Researchers emphasize the need for stronger collaboration between neuroscience and education communities to develop a shared language that facilitates the application of neuroscientific knowledge in educational practice (Pineda et al., 2025; Khakimova et al., 2025; Elgavi & Hamo, 2024).

Overall, the discussion demonstrates that neuroeducation represents a promising approach for optimizing cognitive development during early childhood by aligning educational practices with neuroscientific knowledge about brain development. However, despite the growing body of research supporting neuroeducation, significant gaps remain between scientific evidence and educational practice. Bridging this gap requires improved teacher training, stronger interdisciplinary collaboration between neuroscience and education researchers, and the development of practical frameworks that translate neuroscientific insights into effective classroom strategies. Through these efforts, early childhood education systems can better utilize the "golden period" of brain development to support children's long-term cognitive, emotional, and social development.

CONCLUSION

The findings of this study indicate that early childhood represents a critical "golden period" of brain development in which high levels of neuroplasticity make the developing brain highly responsive to environmental stimulation. Neuroeducation offers a scientifically grounded approach that integrates neuroscience insights with early childhood education practices to optimize children's cognitive, emotional, and social development. The analysis shows that neuroscience-informed strategies such as play-based learning, music activities, socio-emotional learning, and early numeracy experiences can strengthen neural connectivity and support the development of executive functions and cognitive abilities in young children. However, the study also reveals a significant gap between advances in neuroscience and the actual practices implemented in early childhood education settings, particularly due to limited teacher knowledge of brain development, insufficient professional training, and the persistence of traditional teaching approaches. Therefore, optimizing cognitive development in early childhood requires stronger integration of neuroeducation principles into teacher training, curriculum design, and classroom practice, so that educational environments can more effectively utilize the sensitive period of early brain development.

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