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Effects of Neuroplasticity-Based Adaptive Physical Education Learning Model on Motor Development in Early Childhood

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A B S T R A C T

This study aimed to analyse the influence of the neuroplasticity-based adaptive physical education learning model on motor development in early childhood and to understand teacher experiences in designing and implementing this learning strategy. The study employed a quasi-experimental one-group pre-test–post-test design, complemented by a qualitative case study approach. The study participants consisted of 25 children aged 5–6 years and a class teacher at a kindergarten selected purposively. Quantitative data were obtained through motor development tests administered before and after the implementation of adaptive physical education. Quantitative data analysis was conducted using descriptive-comparative analysis to compare pre-test and post-test scores on child motor development. Meanwhile, qualitative data were collected through participant observation, semi-structured interviews, and documentation analysed using an interactive analysis model that included data reduction, data presentation, and conclusion drawing. The results showed an increase in child motor development scores after the neuroplasticity-based adaptive physical education intervention. Qualitative findings revealed three main themes, namely adaptation of activities to individual child needs, increased self-confidence and involvement in child movement activities, and strengthened social interactions during the learning process. These findings suggest that varied and progressive movement stimulations can support optimal motor development through contextualized learning that is responsive to the characteristics of early childhood. This research provides theoretical contributions to the integration of neuroscience with early childhood physical education, as well as practical implications for the development of more adaptive and evidence-based learning models in early childhood education settings.

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INTRODUCTION

Motor development in early childhood is often an early indicator of a child readiness to engage in more complex learning processes, both physically and psychologically. Coordinated movement skills, stable body balance, and the ability to control emotions during activities demonstrate that motor development is not only related to physical aspects but also to a child cognitive and socio-emotional development (Khanjari, 2024). Recent research also shows that well-developed motor skills are associated with long-term health, cognitive function, and child social-emotional development (Saez et al., 2025). From a developmental neuroscience perspective, early childhood is a sensitive period when the brain forms and strengthens neural networks through neuroplasticity mechanisms. During this phase, everyday learning experiences, including physical activity, play a crucial role in shaping brain structures and functions (Silva & Arida, 2015). Physical activity that is consciously and contextually designed has been shown to improve motor coordination (Nurulita et al., 2024), postural control, and even executive function. Unfortunately, in many early childhood education contexts, physical education is often understood as merely a time-filling activity or daily routine, not positioned as a planned and meaningful neurobiological stimulus (Rhim et al., 2020).

A similar situation is also evident in the national context. Field observations and initial interviews with early childhood education teachers indicate that physical education is generally conducted with a uniform approach. Children are asked to repeat the same basic movements, in nearly identical durations and patterns, without much adjustment to accommodate differences in motor skills, attention levels, or emotional regulation. Many teachers rely on years of teaching experience, but this is not supported by a learning model based on a scientific understanding of child brain development (Darling-Hammond et al., 2020). This situation, although often unconscious, has the potential to result in suboptimal motor stimulation, especially for children who require an adaptive approach. Research on neuroplasticity confirms that the quality of activity, the variety of movements, and the social and emotional context during movement significantly influence changes in brain structures and functions related to motor and cognitive development (Terry et al., 2020).

This issue becomes even more relevant from an educational and socio-cultural perspective. Non-adaptive physical education risks widening the developmental gap between children from an early age, a situation that can have long-lasting impacts throughout their education. Early childhood education plays a strategic role in providing inclusive learning experiences that are aligned with child developmental characteristics. Neuroplasticity-based physical activity serves not only as physical exercise but also as a learning space that integrates movement (Dayan et al., 2012), emotions, social interactions, and meaningful experiences. Therefore, the development of adaptive physical education models is becoming increasingly relevant to address the increasingly diverse and complex needs of early childhood education practices (Nelson et al., 2021).

Although a number of studies have demonstrated a positive relationship between physical activity and child motor development, most of these studies tend to use quantitative approaches that focus on end-results, such as improvements in motor skill scores or specific cognitive functions. These studies relatively rarely explore the learning process in depth, including how teachers design physical activities, how children respond to these activities, and how learning adaptations occur in the real-world context of early childhood education (ECE) settings. Furthermore, the concept of influence in physical education research is often

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narrowed down to statistical cause-and-effect relationships, thus failing to fully capture the dynamics of learning as a contextual pedagogical process influenced by interactions between teachers, children, and the learning environment (Adolph & Hoch, 2019). This condition indicates a research gap between studies that quantitatively assess the impact of physical activity and research that explains the process of implementing adaptive physical education learning in early childhood education practices.

Conceptually, the neuroplasticity-based adaptive physical education learning model in this study is based on the principle that varied, challenging, and repeated motor experiences can strengthen neural connectivity and increase the nervous system efficiency in controlling movement. This model emphasizes three main aspects, namely variations in movement activities, progressive repetitions, and adjustment of activities based on the child individual characteristics and needs. This approach aligns with neuroplasticity theory, which explains that meaningful movement stimulation can encourage changes in brain structures and functions related to learning and motor development (Hilderley et al., 2023).

Based on the description, this study aimed to examine the influence of the neuroplasticity-based adaptive physical education learning model on the motor development of early childhood while understanding the dynamics of the implementation of this learning in educational practice. Specifically, this study sought to answer two research aims: (1) whether the implementation of the neuroplasticity-based adaptive physical education learning model had an effect on improving the motor development of early childhood and (2) how the teachers experienced and children responded during the implementation of this learning model. In line with these objectives, the research hypothesis states that the implementation of the neuroplasticity-based adaptive physical education learning model has a positive influence on the motor development in early childhood. Theoretically, this study is expected to enrich the study of early childhood physical education based on developmental neuroscience. Meanwhile, practically, the results of the study are expected to be a reference for teachers and early childhood institutions in designing more adaptive, reflective, and sustainable physical education learning.

METHODS

This study used a quasi-experimental design with a one-group pre-test–post-test model, enriched with a qualitative case study, to understand the learning implementation process. This design was chosen because, in the context of early childhood education, randomization of subjects is difficult due to class constraints and institutional policies. However, it still allows for observation of changes in motor development before and after the intervention (Obrusnikova & Cavalier, 2018; Shadish et al., 2002). The research subjects consisted of children aged 5–6 years at an Islamic kindergarten.

Motor development was measured using a motor assessment instrument adapted from a standard child motor development instrument developed based on the concept of basic motor skills, which was then adapted to the context of early childhood physical education. The instrument validity was tested through the expert judgment by an early childhood physical education expert, while its reliability was analysed using an internal reliability coefficient to ensure the measurement consistency. Quantitative data were analysed by comparing pre-test and post-test scores to observe changes in motor development, while qualitative data were collected through participant observations, semi-structured interviews, and documentations to track the teacher adaptation of activities and child responses during

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learning (González et al., 2025). The integration of these two approaches allowed this research to answer not only whether changes occurred, but also how the pedagogical process took place contextually in everyday learning practices (Yin, 2017).

Participants and Samples

Participants of this study involved 25 early childhood children aged 5–6 years, consisting of 12 boys and 13 girls, all of whom were registered as students at an Islamic kindergarten. In addition, this study also involved the kindergarten teachers who played an active role and were directly involved in the implementation of physical education during the research process. The child demographic characteristics included middle socioeconomic backgrounds, varying early motor skills, and no severe neurological disorders. The participating teachers had a minimum educational background of a Bachelor degree in Early Childhood Education. These characteristics were considered important to ensure the appropriateness of the research context to physical education practices in early childhood education environments and to support the possibility of limited analytical generalization.

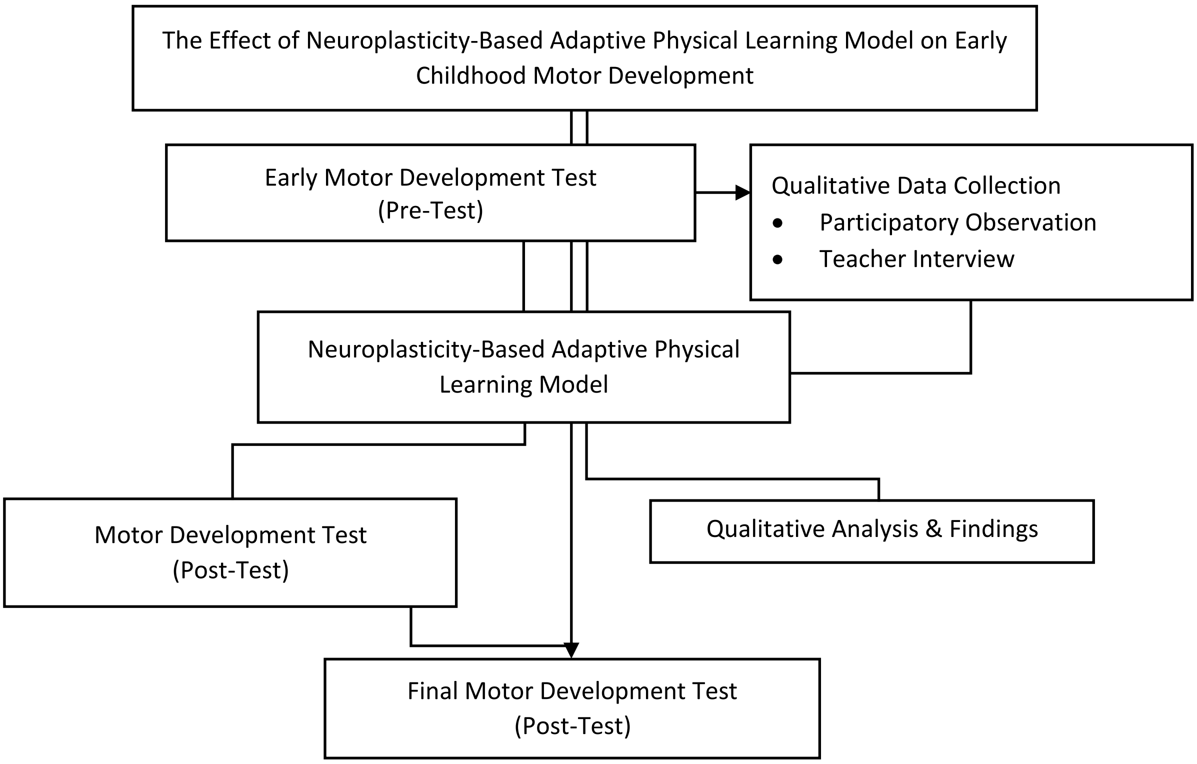

Figure 1. Research Frameworks

The purposive sampling technique was used to select institutions and teachers who had implemented physical education regularly and were willing to participate in the entire series of research interventions (Ames et al., 2019). All children in one class were recruited as research participants to minimize the potential for treatment bias during the learning process. All 100% of approached participants expressed their willingness to participate after receiving a full explanation of the study objectives and procedures. The research activities were conducted in a school environment during regular school hours without any financial incentives to participants, while still taking into account relevant ethical and pedagogical considerations, given that the research subjects were young children. However, the limited involvement of participants in one class and one educational institution indicates that the

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scope of this research is still relatively narrow. Therefore, this research is positioned as an exploratory or pilot study aimed to provide an initial overview of the potential application of a neuroplasticity-based adaptive physical education learning model in the context of early childhood education. This approach allowed researchers to gain an initial understanding of the dynamics of learning implementation and changes in the child motor development after the intervention. The resulting findings are expected to form the basis for further research with a larger sample size, a wider variety of institutional contexts, and a more robust experimental design to enhance the external validity of the research findings. Figure 1 presents the research framework and Table 1 provides details of the research procedures.

Table 1. Research Procedures

Phase	Duration	Activity	Information
1. **Preparation**	2 weeks	1. Management of research permits and ethical approvals for institutions and parents 2. Socialization of the objectives, procedures, and benefits of research to teachers and parents 3. Teacher training on the application of the adaptive physical education learning model based on neuroplasticity 4. Trial and refinement of child motor development observation instruments	Ensuring administrative readiness, research ethics, teacher understanding, and instrument suitability before conducting the research
2. **Pre-test**	1 week	1. Early measurement of child motor development using standardized observation sheets 2. Assessment of basic motor skills (locomotor, balance, and object control) before the intervention	Measuring the initial motor skills of all participants as baseline data before treatments
3. **Intervention**	8 Weeks	1. Implementation of an adaptive physical education learning model based on neuroplasticity 2. Learning was carried out 3 times per week with a duration of 40–50 minutes per meeting. 3. Provision of motor stimulations tailored to the needs and developmental characteristics of children 4. Continuous observation of child motor responses and engagement during the learning process	Providing systematic motor stimulation to optimize the adaptation of neuroplasticity and motor development of children
4. **Post-test**	1 week	1. Final measurement of motor development of the children using the same instrument 2. Observation of changes in motor skills after the intervention 3. Collecting qualitative feedback from teachers regarding learning effectiveness	Measuring the final results of motor development of the children and obtaining supporting data regarding the effectiveness of the learning model

The research instrument used in this study was an observation sheet for early childhood motor development compiled based on gross motor development indicators, including locomotor skills, balance, and object control. This instrument was designed to observe changes in child motor skills before and after the implementation of the neuroplasticity-based adaptive physical education learning model. In addition, learning observation guidelines were

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used to record the intervention implementation process as well as child motor responses and involvement during activities. A semi-structured interview guide was also used to explore the teacher perceptions and experiences regarding the effectiveness of the learning model. Supporting instruments in the form of documentations were used to strengthen the validity of the research data.

Data Analysis

Quantitative data analysis was conducted descriptively and comparatively to compare the pre-test and post-test results of the child motor development. Meanwhile, qualitative data were analysed using the Miles and Huberman interactive analysis model, involving iterative data reduction, data presentation, and conclusion drawing (Huberman, 2014). Data validity was maintained through the triangulation of methods and sources, member checking with participating teachers, and an audit trail to ensure transparency in the analysis process. This approach allowed for in-depth interpretation of the impact of neuroplasticity-based adaptive physical education as a contextual and meaningful learning process.

RESULTS

The quantitative analysis results showed significant changes in motor development in early childhood following the implementation of a neuroplasticity-based adaptive physical education model. Descriptive statistics presented in Table 2 show the distribution of motor development scores before and after the intervention.

Table 2. Descriptive Statistics

	N	Minimum	Maximum	Mean	Standard Deviation
Pre-test	25	16	32	23.60	5,672
Post-test	25	48	64	55.64	5,894
Valid N (Listwise)	25				

The descriptive statistics table shows a clear difference between the pre-test and post-test results of early childhood motor development after the implementation of the neuroplasticity-based adaptive physical education learning model. At the pre-test stage, of the 25 children studied, motor development scores were in the range of a minimum of 16 and a maximum of 32 with an average value of 23.60 and a standard deviation of 5.672. After the intervention, the post-test results showed a substantial increase with a minimum score range of 48 and a maximum of 64, the increased average value of 55.64, and a standard deviation of 5.894. The average difference of 32.04 points indicates a considerable increase in the child motor performance after participating in the adaptive physical education learning intervention.

To clarify these changes, a graphical representation is presented in Figure 2, which compares the average motor development scores at the pre-test and post-test stages. The graph shows a sharp increase in the average scores after the intervention, indicating that most children experienced improved motor skill development after participating in the neuroplasticity-based adaptive physical education program.

The graph in Figure 2 shows a clear difference between motor development scores before and after the implementation of the neuroplasticity-based adaptive physical education model. The average motor development score increased from 23.60 in the pre-test to 55.64

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in the post-test, indicating an improvement in child motor skills after participating in the learning intervention.

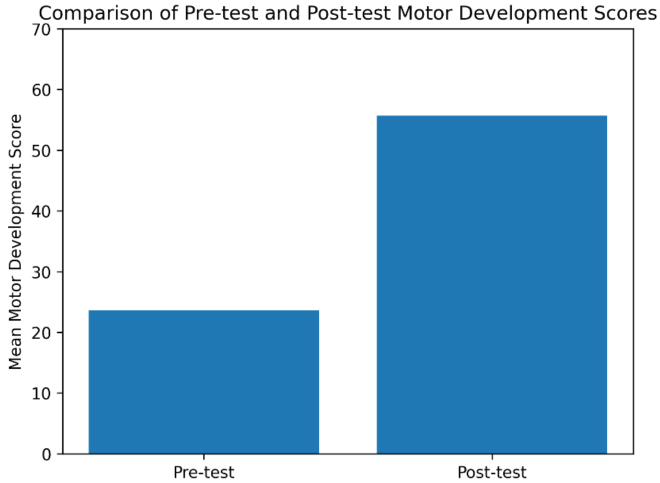

Figure 2. The Comparison between Pre-test and Post-test Average Motor Development Scores

Table 3. Statistical Test

	Post-test – Pre-test
Z	-4.375b
Asymp. Sig. (2-tailed)	0.000

a. Wilcoxon Signed Ranks Test
b. Based on negative ranks

Inferentially, the difference analysis was performed using the Wilcoxon Signed Ranks Test because the data were paired and not assumed to be normally distributed. The test results presented in Table 3 show a Z-value of -4.375 with an asymptotic significance value (Asymp. Sig. 2-tailed) of 0.000 (<0.05). This value indicates that there is a statistically significant difference between motor development scores before and after the intervention. The negative direction of the Z-value indicates that most of the change ranks are in the positive ranks category, meaning that the post-test scores are consistently higher than the pre-test scores.

In addition to statistical significance, the analysis also considered the effect size to understand the strength of the intervention impact. The Wilcoxon test calculated the effect size ($r=Z/\sqrt{N}$). With a Z value of –4.375 and a number of participants of N = 25, the effect size was obtained at r = 0.875. Based on the effect size interpretation criteria, this value falls into the very large effect category, indicating that the neuroplasticity-based adaptive physical education learning model has a very strong influence on improving early childhood motor development. Thus, the results of the quantitative analysis not only show statistically significant differences, but also show that the learning intervention has a large practical impact on the child motor development.

In addition to statistical data, this study also produced qualitative findings that provide a deeper understanding of the process of change in child motor development during the learning intervention. Qualitative data were obtained through participant observations, semi-structured interviews with teachers, and documentations of learning activities.

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Qualitative data analysis was conducted using an interactive analysis model, including data reduction, data presentation, and iterative conclusion drawing as described by Miles and Huberman (Huberman, 2014). The analysis process began with open coding, which identified units of meaning from observation notes and interview transcripts. Next, codes with similar meanings were grouped through axial coding to form conceptual categories. The next stage was theme development through an interpretation process that connected these categories to the context of neuroplasticity-based adaptive physical education. The validity of the findings was maintained through the triangulation of data sources, member checking with participating teachers, and an audit trail to ensure transparency in the analysis process

Participant observations showed that children who initially struggled with coordination and balance gradually showed improvements in motor skills. Teachers actively adjusted the difficulty level of movement activities based on the child individual abilities, ensuring each child could participate optimally in learning activities. A child expressed his experience by saying, "I can now long jump without falling," reflecting increased motor skills as well as self-confidence in carrying out movement activities. The teacher also explained that varying activities and adjusting the difficulty level of the movements help children feel challenged without feeling stressed, so that the learning process becomes more meaningful.

The second theme relates to child increased self-confidence and active engagement in physical education activities. Interviews with teachers revealed that a neuroplasticity-based learning approach allowed teachers to respond more flexibly to child developmental needs. A teacher stated, “By adapting activities, I see children who are usually passive become more willing to try.” Documentations in the form of activity photos and field notes also showed that the learning atmosphere had become more positive and participatory. Children appeared more active in trying various movement activities, indicating increased motivation and engagement in the learning process.

The third theme relates to the emergence of social dynamics during physical education learning. Observations showed that when activities were designed for small group or pair work, children demonstrated better coordination and cooperation skills. In some movement activities, children supported each other and helped their peers complete specific movement tasks. This demonstrates that physical education not only contributes to the development of motor skills but also strengthens child social interactions and collaborative skills. These findings indicate that the social context of learning plays an important role in enriching child motor learning experiences, so that motor development is not only influenced by physical exercise alone, but also by the dynamics of social interactions that occur during learning activities.

DISCUSSION

The results of the study indicate that the implementation of a neuroplasticity-based adaptive physical education learning model significantly impacts the motor development of early childhood. The increase in motor scores on the post-test compared to the pre-test indicates that the systematically designed physical activity significantly improves child motor skills. This finding aligns with previous research showing that structured physical activity could improve basic motor skills in early childhood (Purwanto, 2022). In addition, these results are also consistent with empirical evidence showing that the physical activity carried out continuously contributes to improving coordination, balance, and other motor functions in children (Mcdonough et al., 2020).

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From a neuroplasticity perspective, the improvements in motor performance found in this study can be explained by the nervous system adaptation mechanisms resulting from repeated motor stimulations. Physical activity involving various movement patterns, such as running, jumping, and catching a ball, provides consistent sensorimotor stimulations to the nervous system. This stimulation can trigger the formation of new synaptic connections and strengthen neural pathways associated with motor control. Systematic reviews have shown that physical activity can increase the production of neurotrophic factors, such as brain-derived neurotrophic factor (BDNF), which plays a role in supporting brain plasticity and improving motor and cognitive functions (Fernandes et al., 2020). Therefore, the improvements in motor skills observed in the children in this study likely result from neural adaptation processes that occur through repeated and structured motor experiences during the learning process.

In addition to these biological mechanisms, the adaptive learning strategies implemented in this study also play a crucial role in supporting child motor development. Learning designed with individual differences in ability in mind allows each child to receive challenges appropriate to their developmental level. Teachers adjust the difficulty level of the movements, the variety of activities, and the intensity of the exercises so that children remain challenged but avoid frustration during the learning process. This approach aligns with the principle of neuroplasticity, which emphasizes the importance of repetition, variation, and gradually increasing challenges in strengthening neural connections related to motor skills (Guzmán-muñoz et al., 2025; Čoh, 2021; Sigmundsson et al., 2017). In other words, adaptive learning strategies not only support the improvement of motor skills, but also create optimal learning conditions for the neural changes that underlie child motor development.

The qualitative findings in this study also indicate that social interactions during the learning process contribute to increased engagement in physical activity. When children engage in movement activities in small groups or pairs, they not only practice motor skills but also develop the ability to work together, provide mutual support, and increase self-confidence. Physical activities that involve social interactions have been shown to strengthen child motivation and engagement in the movement learning process, ultimately contributing to overall motor skill improvement (Purwanti, 2025; Pradnyani et al., 2024; Dewi et al., 2023). This shows that physical education for early childhood should not only focus on the physical exercise aspect, but also consider the social and emotional dimensions of the learning process.

From a pedagogical perspective, the results of this study provide important implications for early childhood education practices. A physical education learning model based on the principles of neuroplasticity emphasizes the importance of diverse, repetitive, and progressive movement experiences to support child motor development. Therefore, early childhood educators need to design physical education learning activities that not only emphasize physical activity but also consider aspects of adaptation to the child individual needs. Strategies such as using a variety of movements, providing gradual challenges, and organizing activities collaboratively can help create a learning environment that supports motor development while increasing child motivation and participation. Thus, a neuroplasticity-based adaptive physical education approach can be an effective alternative pedagogical strategy in supporting the holistic motor development of early childhood.

Although this study shows positive results, there are several limitations that need to be considered when interpreting the findings. First, the sample size was relatively small, involving only 25 early childhood children, so generalizing the results to a wider population requires caution. Second, this study did not use a control group, so the improvements in

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motor skills that occurred could not be fully compared with those of a group that did not receive the intervention. Third, this study was conducted at only one early childhood education institution, so different learning environments might produce different findings. Furthermore, individual variations in child motor development might also be influenced by other factors such as parental support, physical activity habits at home, and the developmental characteristics of each child, which were not fully controlled for in this study design.

Considering these limitations, further research is recommended to involve a larger sample size and use an experimental design with a control group to provide stronger evidence regarding the effectiveness of the neuroplasticity-based adaptive physical education model. Furthermore, research in various educational institutions with varying student characteristics is also needed to broaden understanding of the application of this learning model in more diverse early childhood education contexts.

CONCLUSION

This study concludes that a neuroplasticity-based adaptive physical education model significantly improves motor development in early childhood. Improved pre-test and post-test scores, reinforced by qualitative findings, indicate that varied, progressive, and individually tailored movement stimulation optimizes locomotor skills, balance, and object control. A responsive learning process and collaborative atmosphere contribute to strengthening child engagement and self-confidence. Theoretically, this study emphasizes the importance of integrating neuroplasticity principles into early childhood physical education. Practically, these findings serve as a reference for early childhood teachers in designing adaptive and evidence-based learning. Further research is recommended to utilize experimental designs with control groups and broader sample sizes to strengthen the generalizability of the findings.

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AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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