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The intersection of brain development and pedagogy: Comparative analysis of international neuropedagogical models and their potential for domestic application

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ABSTRACT

Driven by neuroscientific research, early childhood brain development has become a significant focus area in pedagogy in the past few decades. This paper presents the foundations of neuropedagogy, focusing particularly on how brain plasticity shapes early education opportunities and possibilities and provides a comparative analysis of neuropedagogical research and programs in the United States and Thailand, highlighting international practices in language development, executive function (EF), and social-emotional skills development. Although their resources and educational systems differ, the two countries have emphasized research on the neurodevelopmental impact of early childhood experiences and interactions. Drawing on these global findings, this study offers suggestions for enhancing Hungary's neuropedagogical approach to early childhood education. Special attention is given to the possibilities for improving Hungarian teacher training, practical kindergarten education, and parental cooperation. The authors put forward concrete recommendations and suggestions: the introduction of EF development programs, the modernization of teacher training, and the creation of a national knowledge-sharing platform. The study outlines that brain-friendly education for young children is more than a scientific mission. It is also a social and human mission that improves the foundations for children's long-term psychological well-being, learning success, and community development.

Introduction

Environmental influences, particularly educational interactions, have long-term impacts on the child's neurodevelopment during early childhood. Using international best practices (EF development programs, language stimulation, mindfulness) can contribute to increasing the effectiveness of kindergarten education and laying the foundations for learning skills. Neuropedagogical approaches and scientific knowledge about brain development are currently under-represented in teacher training. Filling this gap is vital for enabling future kindergarten teachers to respond more consciously and effectively to children's developmental needs, particularly children with disadvantages or developmental risks. The study also provides scientific evidence that the early childhood years are crucial for estab-

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lishing learning skills, emotional stability, and social behavior. Integrating neurobiological research into educational practice can help ensure that children are placed on an optimal developmental trajectory with long-term benefits for society.

Literature review

The early years of childhood are critical for brain development. Neuroscience research over the past decades has revealed how early changes in brain structure, maturation, and plasticity underpin a child's development. This knowledge helps to understand and shape early educational practice from a neuropedagogical perspective. Recent advances in neuroscience have revealed a wealth of new knowledge about the neurobiological features of early childhood. A child's brain is immature at birth but grows and organizes at an astonishing rate during the first few years of life. By the age of three, the brain has more than a thousand trillion synaptic connections (Schiller, 2010; cited in Varga, 2015). In the "use it or lose it" principle, active neural pathways stimulated by the environment are maintained and strengthened, while those not in use disappear, adapting the brain to unique environmental conditions. The brain is highly plastic in early childhood and open to environmental influences that effortlessly shape brain networks, i. e., well malleable. The high plasticity presents significant opportunities and responsibilities to support learning and development. It also reveals vulnerability, as adverse influences can leave a deep imprint on the developing brain. Brain plasticity gradually decreases with age as an increasing number of connections are made, underscoring the importance of appropriate stimulation in the early years, as higher-order abilities build on previously constructed foundations in a hierarchical process (Tierney & Nelson III, 2009). Babies exposed to severe stress from infancy onwards may have lower brain activity than peers raised in calmer environments. Fewer neural connections and pathways develop in the brains of children who do not receive enough attention, stimulation, and affection. Such structural differences also manifest at the behavioral level due to cognitive deficits, which can later manifest in learning and behavioral problems as well as lower school performance (Nelson et al., 2020).

Early childhood is, therefore, a critical period in life when developmental psychological processes (cognitive, emotional, and social development) and neurodevelopmental maturation happen simultaneously and interact. Appropriate support during this initial period—providing a safe, stimulating, and loving nurturing environment—has been scientifically proven to be a long-term return on investment, laying the foundations for healthy psychological functioning, learning skills, and later success in life (Heckman, 2011). It is no coincidence

that recent educational research and practice have focused on the question of how to best support early childhood development, with particular emphasis on applying neuroscience findings in educational practice. This connection forms the basis of neuropedagogy, which has shed new light on early childhood education over the past decade and a half. According to the insights of neuropedagogy, pedagogical work in the early years extends far beyond the transfer of knowledge. It affects the development of a child's brain architecture, self-regulation, and learning skills, patterns of stress management, and social sensitivity. Thus, a teacher not only teaches but also shapes, organizes, and stimulates. A child's educational experience can strengthen or weaken brain connections (Varga, 2015, 2019).

The interdisciplinary science and research field, informed by national and international scientific discourses and innovations on early childhood, seeks answers to the pedagogical potential of the latest neuroscience research findings in early childhood (Varga, 2019). In its attitude research, the Early Childhood Neuropedagogy Research Group and Laboratory (NeuPedLab) at the Benedek Elek Faculty of Pedagogy of the University of Sopron (Hungary) is interested in the attitudes and knowledge of Hungarian teachers towards neurosciences and their views on their pedagogical use. The research observed that although teachers are interested in new knowledge, their proactivity in research and innovation is low, indicating that neuropedagogical approaches are under-represented in teacher education. Providing neuroscience-related knowledge in teacher education should be urgently promoted to enable teachers to integrate modern scientific findings more effectively into their daily work (Varga & Szécsi, 2018; Varga, 2019). The United States has witnessed major scientific and practical breakthroughs in early childhood brain development research and related pedagogical applications in the last decade. Leading American universities, such as Harvard, MIT, Stanford, Yale, and UCLA, have launched large-scale research programs to integrate the latest neuroscience findings into early childhood education.

Brain imaging studies have confirmed that the brain networks that aid in understanding and experiencing the mental states and physical sensations of others are already functioning separately by the age of three (Richardson et al., 2018). Researchers at the Massachusetts Institute of Technology (MIT) have demonstrated that these networks are highly active and plastic in the early years of life, so the quality and frequency of interactions have a significant impact on their network functioning. The ecobiological model of Jack Shonkoff et al. (2012) demonstrates that the "building architecture" of a child's brain is deeply dependent on lived experiences. Stress, emotional security, rich or poor environmental stimuli all leave lasting traces on neurobiological development. Of particular inte-

rest is the study of language development. In a functional MRI-based study, Romeo et al. (2018) demonstrated that the frequency of parent-child dialogue is directly related to activating the left Broca's area, the center of language processing. Children who had more quality dialogues with their parents exhibited increased brain activity and performed better on language tests. Notably, the effect was independent of sociodemographic background—i.e., it was not the number of words heard but the active, reciprocal communication that mattered. This result highlights that the preschool environment and teacher-child interactions may have similar neurobiological effects.

The leaders of the Harvard Center on the Developing Child stress that the neural basis of such "serve and return" interactions justifies their conscious use in educational practice. Frontiers of Innovation, a program launched by the center, aims to identify and field-test the most promising intervention options. The accessible InBrief series helps educators and policymakers to keep up to date with the latest neuroscience knowledge (Center on the Developing Child at Harvard University, 2024).

Reach Every Reader, a joint initiative of MITili, the Harvard Graduate School of Education, and Florida State University, aims to ensure that all children have adequate reading skills by the age of three. The program develops personalized learning pathways and diagnostic tools for early identification of reading disabilities. MRI scans can identify brain patterns in preschoolers that may indicate a risk of dyslexia (MIT News, 2018). This kind of prediction offers the potential for targeted and timely intervention, preventing school failure.

The development of executive function regulation—working memory, inhibitory control, and cognitive flexibility—also peaks at this age. Rueda et al. (2012) have demonstrated that these abilities can be developed through targeted educational interventions and even lead to detectable changes in brain functioning. Neville et al. (2013) developed an attention development program for children of low socioeconomic status and their parents. The results—improved behavior, stronger selective attention, increased brain responses—proved that a holistic, family-inclusive approach can be particularly effective.

In parallel with US research, Thailand has made significant strides towards the targeted development of executive functions (EF) in early childhood. One milestone was a national study launched in 2017 to create a standardized EF measurement tool. Developed in collaboration between Mahidol University and the Health Systems Research Institute (HSRI), the MU.EF-101 is a 32-item behavioral scale that assesses preschool children's behavior in five key areas based on teacher observation, inhibition, shifting/resilience, emotion regulation, working memory, and planning. The normative data for the scale were derived from approximately 3000 children representing various regions of Thailand. It

was the first national survey to systematically provide data on EF skills of preschool children, providing a gap-filling basis for further development. Inhibitory control and self-regulation are high-priority areas among the components of EF, weaknesses that can often lead to attention deficit and hyperactivity. To develop this area, a preschool mindfulness program has been developed (Lertladaluck et al., 2021) to strengthen children's attention and self-control through mindful presence-based practices. The research involved pre-screening using the MU.EF-101 questionnaire. Children with the lowest scores were included in the study. The sample was divided into two groups. In the post-test, the members of the mindfulness group showed significant improvements in working memory and inhibition compared to the control group, both in behavioural observations and cognitive tests, confirming that mindful presence-based pedagogy can be an effective tool for developing self-regulation from preschool onwards.

Imnamkhao et al. (2024) presented another innovative method to improve executive functions (EF). Their program aimed to increase the efficiency of EF components by incorporating playful, health-promoting modules. The eight modules embedded in the kindergarten curriculum included hygiene, body awareness, and movement development. The results of the quasi-experimental study showed that children who participated in the program exhibited significant improvements in all EF domains compared to the control group, thus supporting the idea that playful, experiential pedagogical tools can have a profound impact on executive functioning (Imnamkhao et al., 2024).

The importance of movement-based development was also highlighted by the "I AM TAP" program developed by Pewdee et al. (2024) for disadvantaged preschool children in state care. The program combined sensorimotor and balance activities to advance working memory, inhibitory control, and cognitive flexibility. A distinctive feature of the program was that it considered the children's previous traumatic experiences, including social interaction exercises that promoted joint action and rule-following. Performance in the three main domains of EF had increased significantly compared to the control group by the end of the program, as confirmed by positive feedback from caregivers, including calmer, more focused behavior (Pewdee et al., 2024).

However, EF development can be promoted through programs and qualitative research. Donjdee et al. (2024) investigated the development of inhibitory control in young school children. They found that internal factors (personality traits and sense of responsibility) and external factors (family communication, rulemaking, and moral example) underscore successful inhibitory control. However, the school environment does not directly target such skill development. Instead, it promotes them through indirect strategies (role play, group work, moral stories). The study concluded that the conscious cooperation of both

the family and the teacher plays a key role in the development of self-control (Donjdee et al., 2024).

Objectives, research questions, hypotheses

The present study illustrates the relevance of neuropedagogy in early childhood education, with a focus on how neuroscientific research findings on brain development can be applied to educational practice. It also aims to review neuroeducation-related research and programs in the United States and Thailand. The different frameworks of the two countries also provide an opportunity for a comparative analysis of neuropedagogical research, which may provide insights on how to continue to transfer brain development research findings into pedagogical practice in Hungary.

Methods

The methodological approach of the study is qualitative comparative pedagogical research based on document analysis and systematic literature review. A targeted source analysis has been performed, focusing on international scientific publications, policy documents, and program descriptions in neuropedagogy over the last decade. The sample was selected purposively. The United States and Thailand are used as a point of comparison, as these two countries have different social and educational systems but have seen noteworthy progress in early childhood neuroscience research and its pedagogical applications.

The sources analyzed include descriptions of brain research-based programs, neuroscience studies, results of interventions targeting executive functions, as well as government and university reports. The research uses a qualitative content analysis approach, focusing thematically on sources related to language development, executive functions, social-emotional development, and pedagogical innovation. The results are interpreted comparatively, revealing similarities and differences between the two countries. The study uses these as a basis for making domestic adaptation recommendations to improve teacher education and preschool practice.

Results

There are parallels between the neuroeducational efforts of the US and Thailand, but there are also significant differences due to the different socio-cultural and institutional contexts of the two countries. A growing recognition that the early childhood years are crucial for brain development and later learning abilities exists in both countries, and similar key research focus areas have been observed, including language development, executive function/self-control, and support for social-emotional skills. Researchers in both countries emphasize the role of play, rich stimuli, and affectionate, dialogue-based interactions in optimal brain development. Educational programs based on neuroscience research (e.g., mindfulness in kindergarten, playful EF development, encouraging rich language input) have emerged in the US and Thailand. A further similarity is that the need for interdisciplinary collaboration is universal. Teachers and psychologists do not bear sole responsibility for the field at the center/institution/workshop level. Doctors, biologists, and neurologists also aid in developing training and tools. Both countries also participate in the international scientific discourse—for example, at the International Mind, Brain, and Education Society (IMBES) conferences. American and Thai researchers publish and exchange experiences (Ferrari & McBride, 2011). Similarly, policymakers are beginning to hear the message of science. Strategic plans to improve the quality of early education are emerging at the federal-state level in the US, while Thailand is incorporating support for brain development into its development plans at the national level (one of the objectives of the 2017–2036 education strategy is 'quality early education that is responsive to the specificities of child development'—Thai National Education Plan) (EduBright, 2018). An emerging effort to engage parents and communities is apparent in both countries. In the US, the Harvard Center on the Developing Child and other organizations provide families with accessible information materials. In Thailand, churches, health centers, and community leaders are involved in awareness-raising through, for example, UNICEF's Closing the Gap in ECD campaigns (UNICEF Thailand, 2019).

Nevertheless, marked differences in the nature and application of research between the US and Thailand are evident, which can be attributed to several factors. The United States excels in terms of available resources and technology. US universities have world-class MRI and EEG labs, large research teams, and long-term longitudinal studies involving hundreds of children (e.g., Casey et al., 2018; Gabard-Durnam et al., 2019). In contrast, research in Thailand is typically smaller in scale and focused on short-term studies of practice interventions (Lertladaluck et al., 2021; Jantanavivat et al., 2022). While it is not unusual in the US for a study to report brain imaging results in children, neurological measurements

(EEG, fMRI) with large numbers of children are still rare in Thailand, partly for financial reasons and partly because there are fewer specialists. Thus, results in Thailand are often more indirect. Behavioral test results or teacher observations are used to demonstrate the efficacy of a method, while in the US, changes in activity in specific brain areas are documented, for example, prefrontal cortex thickening after a training session with MRI. Both approaches are valuable. A key reason for the difference is the varying levels of economic and scientific development. The US allocates a larger share of its GDP to research and development, together with substantial private foundation funding (Chan Zuckerberg Initiative, 2025) for educational neuroscience projects. Resources are scarcer in Thailand, which motivates researchers to use more cost-effective methods.

The American educational philosophy is open to innovative experimentation, and individual states and districts are freer to try new methods (America Forward, 2023). Thailand's education system is more centralized and traditional. Introducing new methods is more cautious and considers cultural appropriateness (UNESCO, 2016). For example, American kindergartens are more accepting of children expressing their emotions or vocally arguing because they consider it a part of socio-emotional learning, while the values of harmony and discipline reign in Thai kindergartens, where teachers attempt to develop emotional intelligence through other means (quiet attention exercises) (de Los Angeles-Bantista, 2004). Therefore, neuroeducation research must adapt to the local pedagogical culture. In Thailand, parents and teachers also have reservations about overly 'Western' methods, including the dominance of free play or the ethics of too early brain measurements. Therefore, Thai researchers communicate their findings in the local language and narrative. For example, they articulate the importance of stress reduction in line with Buddhist teachings (Iemamnuay, 2019). Cultural differences also cause some phenomena to differ. For instance, American early childhood is often influenced by other phenomena, including the overuse of digital devices, on which the research focuses and responds (Hirsh-Pasek et al., 2015). However, these issues have been even less reported in research on younger child populations in Thailand.

Early childhood education presents a diverse picture in the US. There are public, private, church, and home-based programs, and funding varies by state. Neuroeducation research also helps convince policymakers that early childhood education is worth the investment (Heckman, 2011). In contrast, Thailand provides much of its early childhood education through a state framework based on a uniform national curriculum. If the "higher powers" adopt a novel approach, it can be implemented in a uniform and widespread way. Hence, the impact of Thai research can potentially be significant and population-wide, but the rigidity of the system makes it more challenging to introduce innovations.

The examples of the United States and Thailand illustrate that neuropedagogy has become a global phenomenon that is being implemented into practice in diverse ways. In the US, the emphasis is on the depth and technological soundness of scientific research, which is then slowly trickling down into everyday practice in the form of programs and recommendations. In Thailand, research is driven by practical needs. The need for better education drives scientific interest, and researchers seek to provide educators with applicable results immediately. Both paths can be fruitful, and the two are not mutually exclusive; indeed, they can learn from each other. The similarities suggest that certain principles are universal: young children need play, meaningful and loving interactions, safety, and challenge to develop. The differences remind us that the application of scientific knowledge is always context-dependent on cultural norms, institutional structures, and available resources.

The Thai experience also provides lessons for international comparisons. It demonstrates that world-class neuroeducational research and applications are possible in developing countries where resources may be more limited, provided that there is an innovative attitude, strategy, and collaboration between academia and education. The example of Thailand suggests that supporting early childhood brain development is one of the most effective investments in education policy. Neuroscientifically equipped teachers and parents can raise a generation of children with better cognitive abilities, greater resilience, and a greater willingness to learn. Neuropedagogy is, therefore, more than a scientific trend; it is also a proven practical guide to education.

Summary and recommendations

In light of the international results, we can take several steps to integrate the knowledge of neurodevelopment in early childhood into the practice of kindergarten education in Hungary, especially at the Benedek Elek Faculty of Education of the University of Sopron.

American and Thai research draws attention to the importance of developing executive functions (EF) in preschool. The present study proposes the initiation of a national longitudinal study to follow the development of self-control and attentional skills in children aged 3–6 and to investigate their relationship with preschool attendance. In this context, it is worth testing an EF development program adapted to the Hungarian setting and measuring its effects on children's cognitive, social, and emotional development. Based on international evidence, it is expected that such an intervention will increase children's engagement and learning success and, in the long term, may contribute to reducing early school leaving.

The study of children with atypical development is a fundamental research field in neuropedagogy. An interesting avenue of research could be to follow the neurodevelopment of preschool children who have experienced birth complications. Exploring the prevalence and effects of toxic stress in the home is also imperative. Examining the number of preschool children who live under persistent stress (e.g., domestic violence, extreme poverty), what signs of this are present in their behavior, and what educational support can be provided to help them is vital. It would be worthwhile to research the capacities and methods for trauma-sensitive education in Hungarian kindergartens to determine gaps. Such research could provide a basis for developing special therapeutic programs for children at risk.

As some research studies have shown (e.g., Varga & Szécsi, 2018; Varga, 2019; Borbás, 2020), the Hungarian teachers interviewed are open to new research on brain development and even consider it necessary to enrich their pedagogical practice with scientific knowledge. These results indicate a need for a neuropedagogical approach in the teaching profession. Organizing a pilot in-service training course where participating teachers would receive targeted neuropedagogical training and then see the changes in their activities with children and in children's development would be beneficial. Such an endeavor would provide meaningful feedback on the content and methods of future training for pre-school teachers to effectively apply the findings of brain research.

Further development of "brain-friendly" kindergarten education practices could also be a positive direction. For example, in light of the research findings, various programs based on pedagogical elements that consciously develop the brain could be developed in the University of Sopron's kindergarten practice and partner institutions. As part of the daily routine, it could be useful to include playful self-control exercises, such as rule games, relaxation corners, and simple breathing exercises. Involving parents in "serve and return" would be an added dimension. A program incorporating these elements could first be piloted in a group at the University of Sopron's kindergarten and then compared with traditional groups. If the experience is positive, the program could be gradually extended. This model must integrate the existing values of Hungarian pre-school education, since Hungarian pre-school education has world-class achievements in the fields of play, fairy tales, art, and music education.

A national online knowledge-sharing platform where teachers publish their best neuropedagogical ideas and lesson plans could also be created. Such a platform would allow teachers to learn from each other and allow for a collection of "best practices" that could then be the focus of a conference, a book of studies, or a practical handbook.

The next step could be the creation of a "Neuropedagogical Workshop" to develop methodological materials and train mentors. For example, a training module for practicing pre-school teachers could be developed to introduce them to the principles of brain-friendly education, with concrete lesson plans and tools. The module could draw on a selection of programs that have been tried and tested in the US and Thailand. Teachers who participate in the mentor network and complete the training can help kindergartens in the process of introducing a new program.

Regular evaluation and monitoring of any newly introduced programs and methods are necessary. If a kindergarten adopts an EF development program, it is appropriate to study the children who have participated in it over a period of years and to compare results with those of children in other kindergartens. Such monitoring would provide evidence of the impact of the program on the home environment, which may be a convincing argument for its further dissemination and adaptation. Once the data and results are known, the methods can be continuously refined. At the level of education policy, it may be possible to measure the impact of the spread of the neuropedagogical approach on macro-indicators such as school performance, SNI rates, and the prevalence of behavioral problems over a span of 5–10 years.

Of course, conference participation and cooperation with major organizations and centers are essential to achieving the necessary knowledge transfer. As part of international cooperation, a cardinal point is to break down any language barriers by translating and making available key technical material. A Hungarian "Neuropedagogical Handbook" or online collection of teaching materials could be developed, bringing together the best international content, tailored to Hungarian conditions.

The Benedek Elek Faculty of Pedagogy of the University of Sopron could creatively transfer this growing body of knowledge to Hungarian practice. The existing values of Hungarian kindergarten education (loving care and education, playfulness, cultivation of folk traditions) can be well complemented by the new achievements of neuropedagogy. Educators in the country are open to innovative approaches and demand a scientific basis, which creates a sound environment for innovation. The next step is to translate strategic vision into practical action, which is in the hands of policymakers and practitioners. If the proposed actions are implemented, the first national data on the results of neuro-educational innovations could be available within the next few years, and, in the longer term, a generation could grow up with education that maximizes their brain development potential. The case for brain-friendly pre-school education is both a scientific and a human mission. Investing in the development of our youngest children is how we build a shared future.

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