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CAN ALL CHILDREN BE EXCELLENT LEARNERS? THE NEUROSCIENCE OF HIGH ACADEMIC POTENTIATION OF SCHOOL CHILDREN

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ABSTRACT

High Performance Learning is potential for all, not just for a few. Neuroscience has explored this human potential, which is not dictated by genes alone but is also influenced by the environment. This study investigates the science behind this through a systematic review of eleven peer-reviewed articles from reputable journals. The review of these articles substantiates the claim that human brains are malleable. The hippocampus, responsible for episodic and spatial memories as well as the regulation of short-term to long-term memory, can be made malleable by strengthening synaptic signals through practice and experience, along with compounds such as flavonoids and brain-derived neurotrophic factors. This understanding can support educators in continuously providing every human brain with opportunities to be activated, allowing these impulses to pass through neural pathways and be stored in brain structures, ultimately achieving higher academic potential.

Keywords: *High performance learning, Neuroplasticity, Educational neuroscience.*

INTRODUCTION

The demands of society necessitate the cultivation of individuals capable of learning new skills. According to the World Economic Forum's Future Jobs Report 2020, four types of skills will be essential in the work environment by 2025: problem-solving, self-management, working with people, and technology use and development. The report specifically highlights the need for data analysts and scientists, AI and machine learning specialists, big data specialists, digital marketing and strategy specialists, process automation specialists, business development professionals, digital transformation specialists, information security analysts, software and application developers, and Internet of Things specialists. If these are the anticipated work requirements, society will increasingly need individuals with more malleable brains to thrive in the future.

In the context of the future of work, education must move away from antiquated models and adopt transformative approaches in schooling and lifelong learning. One such model making inroads in international schools is High Performance Learning (HPL), which challenges educators to rethink every learner’s potential. This shift is scientifically supported by the field of

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neuroscience, which has debunked several myths and provided an accurate understanding of the human brain (National Scientific Council on the Developing Child, 2007). These myths include:

> **Myth 1: Intelligence is Fixed.** This idea dates back a century, with IQ testing schemes proposed by Alfred Binet and Lewis Terman (Cherry, 2023). They believed intelligence could be quantified and was relatively stable over time, with scores representing a fixed trait (Warne, 2020). Stott (1983) highlighted the carelessness and bias in early studies linking brain size and structure directly to intelligence, suggesting biological determinism. Neuroscience has disproven this by presenting evidence of the brain's malleability and demonstrating that intelligence can be developed through experience and practice (Vogel, 2012; Schulz & Hausmann, 2017; Mateos-Aparicio & Rodríguez-Moreno, 2019; Ryszard Praszkier, 2019; Пальцын & Свиридкина, 2020).

> **Myth 2: Left Brain vs. Right Brain.** Parslow (2011) expanded on the oversimplification of this concept, showing that both hemispheres work together, and cognitive functioning requires integrated activity across both hemispheres. Nielsen et al. (2013) found no phenotypic differences between the two hemispheres via neuroimaging data from 1011 individuals aged 7 to 29, revealing that brain hemisphere dominance (lateralization) pertains more to specific networks or brain regions rather than the entire brain.

From debunking these myths and considering the transformative cognitive framework of HPL, two important statements require further exploration within the neurobiological context, which supports the High-Performance Learning Framework (Eyre, 2016):

1. High performance is attainable for all students through systematic instruction.
2. We can systematically teach students how to be 'intelligent' and succeed in school.

This paper reviews recent research articles supporting the neurobiological foundations of high-performance learning. It underscores the importance of transitioning to learning environments that promote cognitive excellence and holistic development using neuroscience as a foundation for change. By fostering these environments, schools can pave the way to becoming outstanding educational institutions.

METHODS OF STUDY

This systematic review of literature structure used in this paper is based on the five steps protocol by Khan et al. (2003) published in Journal of the Royal Society of Medicine. This process is graphically in Figure 1.

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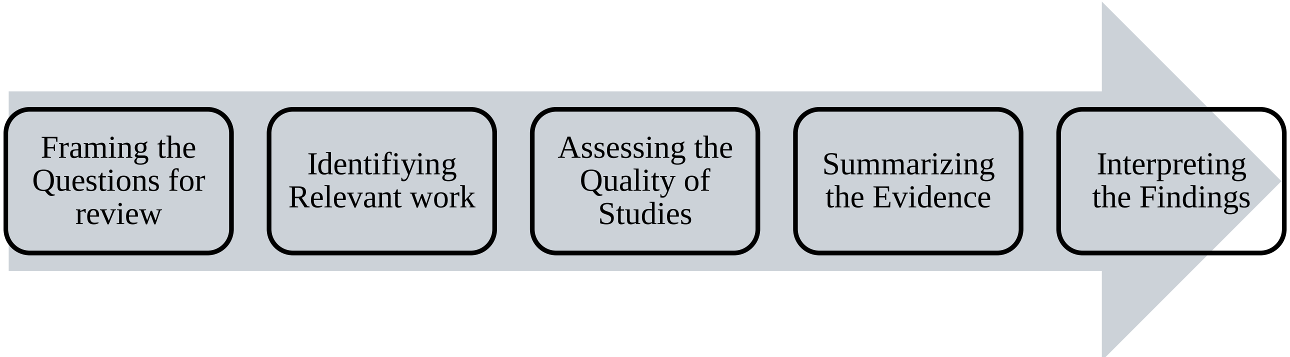

Figure 1: Five Steps to Conducting Systematic Review (Khan et al., 2003)

The literature considered in this paper was suggested by the AI-powered software Elicit (Elicit, 2023), which assists researchers in finding relevant scientific papers. The table below summarizes the literature, supported by keywords and phrases relevant to the research objectives. The main inclusion criteria include peer-reviewed articles from reputable publications, published no later than 2018, and papers that are experimental, observational, or both. Meta-analyses and systematic reviews were also included. The characteristics of the literature used in this paper are presented in the table below.

Table 1: Relevant Literature Profile

Study ID	**Authors and Year**	**Study Title**	**Journal**	**Study Design**	**Quality Assessment**
1	Jeong, N., & Singer, A. C. (2022)	Learning from inhibition: Functional roles of hippocampal CA1 inhibition in spatial learning and memory	Elsevier, Current Opinion in Neurobiology	Systematic Review	High
2	Asan, Rasim Mogulkoc, Abdulkerim Kasim Baltaci, & Dervis Dasdelen. (2022)	Learning, Neurogenesis and Effects of Flavonoids on Learning	Mini Reviews in Medicinal Chemistry	Systematic Review	Moderate
3	Hidayat, R. (2023)	Study of Brain Neuroplasticity Analysis in Response to the Learning Process	Sriwijaya Journal of Neurology	Observational and Analytical Design	High
4	Kennedy, M. B. (2016)	Synaptic Signalling in Learning and Memory	Cold Spring Harbor Perspectives in Biology	Experimental Technique	High

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Study ID	Authors and Year	Study Title	Journal	Study Design	Quality Assessment
5	Langille, J. J., & Brown, R. E. (2018)	The Synaptic Theory of Memory: A Historical Survey and Reconciliation of Recent Opposition	Frontiers in Systems Neuroscience	Systematic Review	High
6	Ma, S., & Zuo, Y. (2021)	Synaptic modifications in learning and memory – A dendritic spine story	Seminars in Cell & Developmental Biology	Experimental design	High
7	Aitchison, L., Jannes Jegminat, Jorge Aurelio Menendez, Pfister, J.-P., Pouget, A., & Latham, P. E. (2021)	Synaptic plasticity as Bayesian inference	Nature Neuroscience	Systematic Review intending to formulate hypothesis	Moderate
8	Kirk, I. J., Spriggs, M. J., & Sumner, R. L. (2020)	Human EEG and the mechanisms of memory: Investigating long-term potentiation (LTP) in sensory-evoked potentials	Journal of the Royal Society of New Zealand	Experimental	High
9	Moore, D., & Loprinzi, P. D. (2020)	Exercise Influences Episodic Memory via Changes in Hippocampal Neurocircuitry and Long-Term Potentiation	European Journal of Neuroscience.	Experimental	Moderate
10	Chen, L., Chang, H., Rudoler, J., Arnardottir, E., Zhang, Y., de los Angeles, C., & Menon, V. (2022)	Cognitive training enhances growth mindset in children through plasticity of cortico-striatal circuit	Npj Science of Learning	Experimental Design	High
11	Pan, Y., Dikker, S., Goldstein, P., Zhu, Y., Yang, C., & Hu, Y. (2020)	Instructor-learner brain coupling discriminates between instructional approaches and predicts learning.	Neuroimage	Observational Study	High

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RESULTS AND DISCUSSIONS

In the context that all students can be high performers and that the school can systematically teach students to be intelligent are viewed by neuroscience as potentiation. Neuroplasticity is the nervous system's ability to change its activity by reorganizing its structure, functions, or connections in response to internal or external factors (Puderbaugh & Emmady, 2023). Advances in neuroscience have further supported this paradigm shift, demonstrating that the brain's regulatory processes can be made malleable through experience and practice (Vogel, 2012; Schulz & Hausmann, 2017). The below review provides neuroscience evidence for the context of high-performance learning.

Assumption 1: High performance is reserved for a select few vs. High performance is attainable for all students through systematic instruction

Learning happens when an animal gains knowledge or skills from experiences. This involves creating new information in the brain, which is initially stored short-term and then made stable for long-term memory through a process called consolidation. The hippocampus is key for quickly learning and storing memories about places and events. In the study of Jeong and Singer (2022), they discussed the role of hippocampus part of the brain in spatial learning and memory. In their study, they discussed that hippocampal cells become active when learning new things, helping us understand our surroundings and remember important details for tasks. These cells work alongside other brain cells that control or inhibit activity, which is crucial for memory functions. In this study, researchers found out that interneurons are critical regulators of principal cell activity, and their cell heterogeneity suggest diverse computational functions in spatial cognition. Issues with these inhibitory cells are linked to memory-related diseases.

The aforementioned findings are supported by the study made by Asan et al. (2022), where they emphasized the role of hippocampus in receiving and storing information in the neocortex. The hippocampus ability for neurogenesis is said to aid in hippocampal dependent learning and memory. The researchers have identified the role of flavonoids in promoting synaptogenesis link to improving cognitive performance and reducing oxidative stress, responsible for hindering cognitive processes.

There is a volume of research that indicates that various types of inhibitory cells in the hippocampus have distinct roles in learning and memory (Andrews-Zwilling et al., 2012; Lovett-Barron et al., 2014; Martinez-Losa et al., 2018; Artinian et al., 2019). These cells vary not only in their genetic makeup but also in how they connect to other cells in the hippocampus, suggesting unique functions in processing information. Recent studies show the diverse functions of these cells, emphasizing their importance in understanding how the brain computes and stores memories.

Hidayat (2023) identifies processes in neuroplasticity involved in learning which includes synaptic changes, structural restructuring and functional plasticity. The study details synaptic plasticity’s correlation to memory formation by altering the strength of synaptic connections. Structural plasticity involves the physical changes in neurons like the growth of new dendrites. Functional plasticity highlights the brain’s ability to reassign functions among its areas based on

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activity levels. These are involved in memory formation, facilitate long-term adaptation and regulate specific functions and tasks.

The billions of neurons in the brain make trillions of synaptic connections. Kennedy (2016) explained the signalling of the different synapses which are a function of learning and memory which then brings to further the process of synaptic plasticity at excitatory synapses. Memories are formed when specific connections (synapses) between neurons become stronger or weaker in response to experiences. This process occurs primarily in the hippocampus, where new neural circuits are quickly created after events. When neurons frequently activate together, their connections strengthen ("neurons that fire together, wire together"), making it easier to trigger future activations. Conversely, if connections do not result in simultaneous activations, they weaken and may eventually disappear. This strengthening and weakening of synapses, known as synaptic plasticity, is crucial for memory formation. Synapses that exhibit this behaviour are called Hebbian synapses. Glutamate, an excitatory neurotransmitter, plays a key role in this process, while other neurotransmitters like GABA, acetylcholine, and various hormones can modulate it but do not show Hebbian behaviour. The process of memory storage via the neurobiological process is supported in the study of Langille and Brown (2018) where they confirm that the synaptic theory of memory is still relevant as opposed to the critique made by Trettenbrein (2016).

Assumption 2: We can systematically teach students how to be ‘intelligent’ and how to succeed in school

There has been evidence to prove that storing information in the brain is influenced by the formation and removal of dendritic spines. In the study by Ma and Zuo (2021), it is emphasized that activity-dependent modification of synaptic structure and function provides a mechanism for learning and memory. When one learns something new or remembers something, the brain's neurons communicate with each other more effectively. This communication happens at synapses, the connections between neurons. When these synapses are active, they can change their shape and how they work. These changes make it easier for neurons to connect and communicate, which helps store new information and create memories. This process of modifying synapses based on activity is essential for learning and memory.

There have been some attempts to explain the relationship between synaptic weights and learning. Aitchison et al. (2021) proposes that synaptic plasticity can be better understood by treating synapses as performing Bayesian inference. Specifically:

1. Synapses compute probability distributions over synaptic weights, rather than just point estimates. This allows them to represent uncertainty about the true weight.
2. Synapses adjust their learning rates based on the uncertainty of the weights. Weights with higher uncertainty led to higher learning rates.
3. Synapses communicate their uncertainty through variability in postsynaptic potential size, where greater uncertainty corresponds to increased variability.

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The Bayesian framework can generalize existing learning rules and provides a normative view of learning that explains the variability observed in synaptic responses. It generates falsifiable predictions for future experiments, making it a robust model for understanding synaptic behavior in neural circuits. Treating synaptic plasticity as Bayesian inference provides a new perspective on how neural circuits learn and adapt. It highlights the importance of representing and communicating uncertainty in neural computations. This approach provides new insights into how neural circuits learn and adapt over time.

While going through different literature, the researcher came across the concepts of long-term potentiation (LTP) as key to learning. As reported by Kirk et al. (2020), when people are exposed to repeated sensory stimuli, certain brain signals increase in strengths and stay strong for a long time. This is observed through changes in sensory-evoked potentials measured by electroencephalography (EEG) which is indicative of the neural encoding of memory. LTP, in this study, features based on experimental evidence, includes stimulus specific, NMDA receptor dependence and individual genes.

Strengthening LTP is vital in recapturing information about unique personal experiences. In the experimental research made by Moore and Loprinzi (2020), the researchers studied the role of exercise in the episodic memory. Episodic memory refers to the ability to store, recapture information about unique personal experiences which are nestled in the medial temporal lobe (Hebscher & Voss, 2020; Kovács, 2020). Numerous studies have explored the neuroscience behind physical exercise (Moore & Loprinzi, 2020), highlighting its positive impact on brain function. Exercise promotes neurogenesis and myelination, which enhance oligodendrogenesis, spatial learning, and memory consolidation. It also strengthens synaptic function, improving neural communication and resilience. Additionally, exercise increases both the quantity and size of dendrites, which in turn boosts the production of Brain-Derived Neurotrophic Factor (BDNF), a protein and key molecule in brain plasticity and cognitive function, responsible for the development, maintenance and plasticity of neurons (Autry & Monteggia, 2012; Kowiański et al., 2017; Zhang & Liao, 2019; Miao et al., 2020).

Chen at al. (2022) experimentally explored the relationship between changes in functional connectivity due to training and improvements in a growth mindset for children. Researchers studied the changes in brain connectivity in four regions (bilateral dorsal Anterior Cingulate Cortex - ACC, right dorsal striatum, and right hippocampus) and linked them to improvements in growth mindset after training. It was found that these changes in brain connectivity significantly explained the variance in growth mindset improvements. This link was not seen in the control group. Additionally, the same brain connectivity changes did not predict changes in math skills. Increased connectivity between the right dorsal ACC and both the left dorsal ACC and the right dorsal striatum was specifically associated with growth mindset improvements in the training group. These findings suggest that brain plasticity in the dorsal ACC and its connections supports growth mindset gains from cognitive training.

Students' success in understanding and retaining information taught by the teacher relies on their brain's readiness to process it. Without this readiness, learning cannot take place. Neuroscience-based learning emphasizes building and reinforcing neural connections and

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networks, thereby enhancing the correlation between learning styles and the improvement of students' metacognitive skills. In the review article of Firmanto et al. (2019), the relationship between neuroscience and metacognition was explored. In their book, they discussed the theory of neuroscience. They claim that the theory of learning neuroscience emphasizes how the brain's functions support the entire thinking process, which includes the generation of knowledge, attitudes, and behaviors. It explores brain activity, nerve functions, and various brain diseases. This understanding is crucial for learning, as a person's ability to absorb information depends on their brain's readiness. The information processing system involves sensory registers, short-term memory (working memory), and long-term memory. Sensory inputs are briefly held and either discarded or sent to working memory, then transferred to long-term memory if retained. Learning involves the formation and strengthening of neural connections, particularly in the frontal and temporal cortices. Observational learning and repetition can alter neural structures, making cognitive tasks routine.

Another interesting study was made by Pan et al. (2020) on instruction-based naturalistic learning using functional near-infrared spectroscopy (fNIRS) hyper scanning. Their studies showed that brain-to-brain coupling was correlated to learning outcomes. Specifically, the coupling was enhanced during instructional interactions characterized by scaffolding behaviours such as asking questions and providing hints rather than going through clarification or listening to explanation.

Recent studies have refined the understanding of the belief in a dominant left or right hemisphere in learning. This concept is now recognized as one of the most widespread misconceptions in education, often referred to as a neuromyth (Geake, 2004; Rousseau, 2020; Lawrence, 2020). Research by Shin et al. (2022) clarifies that while each hemisphere may show a predisposition for managing specific cognitive functions, it is overly simplistic to classify individuals strictly into left or right brain learners. Effective learning necessitates the activation of the entire brain, and significant differences exist in the hemispheric specialization for various tasks. Instead of tailoring educational strategies to fit an outdated notion of hemispheric dominance, a more holistic approach is vital. Educators are encouraged to enhance whole-brain learning by employing diverse instructional techniques and creating varied learning pathways, facilitating extensive practice of critical skills, and promoting students' independence and ability to regulate their own learning. This comprehensive approach not only debunks old myths but also aligns with modern educational best practices that recognize the complexity of brain functions and learning styles.

Incorporating insights from contemporary neuroscientific research, it becomes evident that the notion of left-brain or right-brain dominance, a popular theory in educational discourse, is overly reductive. Advances in brain imaging technologies have elucidated a more intricate picture of cognitive processing, demonstrating that while specific brain regions within each hemisphere may engage more actively in certain tasks, the two hemispheres do not function in isolation. Instead, they are extensively interconnected via the corpus callosum, facilitating robust interhemispheric communication. This complex interplay underpins a range of cognitive activities, highlighting the brain's integrated operational nature.

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From a sociocultural perspective, the endurance of the left-brain/right-brain dichotomy within educational narratives may reflect broader cultural tendencies to categorize and simplify complex phenomena. Such simplifications can inadvertently shape educational practices, potentially constraining the holistic cognitive development of learners by not fully recognizing or leveraging their diverse capabilities.

In response, educators are encouraged to adopt methodologies that reflect a clear understanding of brain functionality, recognizing the integrated and comprehensive nature of cognitive processes. This approach advocates for educational strategies that embrace the full spectrum of cognitive engagements, fostering an inclusive learning environment that accommodates and stimulates various learning modalities and styles. By aligning educational practices with the interconnected and multifaceted dynamics of brain activity, we can enhance the inclusivity and effectiveness of teaching, thereby embracing the complex reality of human cognitive capacity.

CONCLUSIONS

Neuroscience has robustly demonstrated the potential for all children to achieve high academic levels, fundamentally challenging the traditional notions of fixed intelligence and predetermined left-right brain dominance. The field has illuminated the inherent neuroplasticity of the brain, showing its capacity to adapt and reorganize through synaptic plasticity in response to diverse educational experiences. This adaptability is comprehensive, involving various brain structures such as the hippocampus, neocortex, and synaptic dendrites, which, when sufficiently activated through experience and practice, can facilitate high levels of learning—including mastering new and challenging skills.

In response to the question posed in the paper's title, 'Can All Children Be Excellent Learners?', the findings of this paper underscore that with customized educational strategies, every child has the potential to excel. Critical to their development are not only genetic factors but also the availability of connection-enhancing compounds such as flavonoids and brain-derived neurotrophic factors. These elements are essential for boosting learning capabilities.

By leveraging this advanced understanding, educators and policymakers can implement teaching practices that are inclusive and effective, ensuring that every child has the opportunity to excel academically. This approach not only democratizes education but also maximizes the learning potential of every student, affirming the belief that all children can indeed become high-performance learners. With a commitment to integrating these neuroscientific findings into educational methodologies, we can transform the landscape of education to support the high academic potentiation of all school children.

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