

Educational Neuroscience and Vygotsky Sociocultural Theory Can Help for Teaching and Learning: An Overview

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Abstract - This article examines the developmental period that supports learning processes critical for human brain growth and maturation. During the first two and a half decades of life, the brain undergoes substantial development, with learning experiences shaping neural architecture through experience-dependent neuroplasticity. (Villa et al., 2026) The study investigates how both formal and informal learning, which produce lasting and accessible knowledge, are mediated by neuroplasticity, leading to adaptive structural and functional modifications in brain networks. Given that experience-dependent neuroplasticity is most prominent during the school years, this stage offers considerable educational potential. (Milbocker et al., 2024) Neuroscience can inform educators about the brain's inherent learning mechanisms to improve student outcomes. This review adopts a neuroscientific framework to analyze key educational constructs, such as mindset, motivation, meaning-making, and attention.

Keywords: *Educational Neuroscience, Learning development, Neuroplasticity, Knowledge, Brain.*

INTRODUCTION

Educational neuroscience is an interdisciplinary field that investigates the effects of education on the human brain and facilitates the application of research findings to brain-based pedagogies and policies. The brain serves as the primary organ affected by educational processes. Education has been shown to influence both brain development and health, including during aging. (Judd et al., 2020) Examining the interactions between the brain and education is essential for identifying strategies to support learners throughout their lives.

Educational neuroscience investigates the relationships among physiological, psychological, and behavioral factors in learning. Many studies aim to identify the optimal physical conditions that promote neuroplasticity and learning by examining the effects of sleep, physical exercise, and environmental pollution on brain function and cognitive performance. (Pickersgill et al., 2022) Although these studies primarily address how brain health influences learning, other research explores how learning impacts brain health, including the long-term effects of education on neural development and the association between formal and informal education and healthier brain aging. (Chan et al., 2021)

Educational neuroscience further addresses the interplay between genetic and environmental factors in learning by investigating how learning environments interact with genetic conditions and identifying DNA variations that predict differences in learning abilities. Environmental influences on learning are also examined through studies on the impact of socioeconomic status (SES) on brain development and cognitive trajectories. (Tooley et al., 2021). Additionally, educational neuroscience seeks to elucidate the mechanisms underlying general learning abilities, such as executive control and social and emotional skills, as well as discipline-specific abilities, including literacy, numeracy, and science. The field also investigates the relationships among these mechanisms and the degree to which learning skills can be developed through training.

Human development is shaped by genetic factors (nature), environmental influences (nurture), and their interactions (epigenetics). These components are essential to learning processes and to the reorganization of neuronal networks that form representations of newly acquired knowledge. The acquisition and practice of new knowledge or skills induce specific, repeated neural activity patterns. Hebbian neuroplasticity reinforces neural pathways by strengthening particular synapses, while less functional connections are eliminated.

Vygotsky introduced the concept of the zone of proximal development (ZPD) in educational theory nearly fifty years ago. The ZPD asserts that learning and development depend on an optimal balance between support and challenge (see Figure 1: the zone of proximal development and neuroplasticity), a balance that must be tailored to each learner's developmental stage. This model was

transformative because it emphasized the importance of the educational environment (nurture) in realizing students' inherent potential (nature) and prioritized the learning process over learning outcomes as the primary educational objective. Advances in the biology of learning have since demonstrated a strong correspondence with Vygotsky's theory, providing evidence that neuroplasticity is significantly influenced by environmental conditions and the balance between demands (challenge) and available resources (support). (Wenger & Lövdén, 2016) The effects of stressors on learning can be either beneficial or detrimental, depending on their intensity, duration, accumulation, and the individual's coping mechanisms and available support. (Kim & Kim, 2023).

Lev Vygotsky's sociocultural theory aligns perfectly with neuroplasticity—the brain's ability to reorganize and form new neural pathways through experience. Vygotsky's concept of the Zone of Proximal Development (ZPD) serves as the ideal cognitive "stretch zone," where the right balance of challenge and social support strengthens neural connections in the brain. (Wertsch, 1984)

Overview

Neuroscience research demonstrates that experience-dependent neuroplasticity, which underpins learning processes, is regulated by several key principles. (Kleim & Jones, 2008) The acquisition of new skills or knowledge requires the activation of specific neural pathways. (Yin et al., 2009) Additionally, the saliency, intensity, and repetition of the targeted skill or knowledge are identified as effective strategies for facilitating neuroplastic changes. (Duncan et al., 2026) Active engagement in the learning process is essential, as passive reception of information is insufficient to induce meaningful neural adaptation. (Hennig et al., 2021).

Integrating Neuroplasticity into Educational Content

Instruction on experience-based neuroplasticity and the dynamic changes in neuronal networks during learning demonstrates the inherent and robust capacity for learning. (Milbocker et al., 2024,) Furthermore, explicitly connecting neuroplasticity to the growth mindset and developmental processes provides a compelling rationale for learners: learning potential is dynamic and substantially shaped by attitudes and learning practices.

The neuroplasticity principles of “use it or lose it” and “use it to improve it” suggest that, while teachers offer support and guidance, students are ultimately responsible for enacting their own learning. (Growing Brains, Nurturing Minds—Neuroscience as an Educational Tool to Support Students' Development as Life-Long Learners, 2020) This physiological perspective cultivates a sense of responsibility and ownership among students.

Applying Neuroplasticity Principles to Learning Design

Educational environments that promote neuroplasticity model and encourage healthy lifestyles, including regular physical activity, balanced nutrition, sufficient sleep, and effective stress management. (Phillips, 2017) For instance, students should be made aware of the negative impact of sleep deprivation, such as “all-nighter” study sessions, on learning outcomes. (Crowley et al., 2024) In addition, learning systems should emphasize intellectual stimulation through novelty and challenge, and foster a positive social and emotional climate characterized by strong interpersonal connections. Neuroplasticity and development are optimized in the stretch zone, where learners face motivating challenges and stimulation while receiving emotional and social support. (Goldberg, 2022) The balance between support and challenge should be individualized and adjusted over time.

Professional development in neuroplasticity enables teachers to more effectively understand and support students affected by trauma. (Impact of Educational Neuroscience Teacher Professional Development: Perceptions of School Personnel, 2022) Childhood adversity reduces both the duration and extent of neuroplasticity, as a brain oriented toward survival is less capable of learning. (McLaughlin et al., 2019) While early trauma impairs neuroplasticity, it also presents opportunities for recovery. Schools are essential in mitigating the effects of early trauma by creating enriched and safe learning environments that reinforce alternative neuronal pathways, thereby counteracting the negative impact of adverse childhood experiences on brain development. (McDermott et al., 2023).

Learning, Motivation, and Reward Systems

Learning and adaptation are essential for survival and success in dynamic environments. The brain has evolved to process information from both external and internal sources and to generate adaptive behaviors that support survival. (Soltani & Koechlin, 2021) Consequently, the brain inherently functions as a learning system, and learning can occur independently of external initiation. However, learning is highly dependent on experience and can be intentionally directed and enhanced through educational interventions.

The brain's reward system evolved to reinforce effortful behaviors essential for survival, including foraging, reproduction, and caregiving. (Stuber & Wise, 2016) These behaviors activate the dopaminergic system, which is associated with reward and motivation. (Eshel et al., 2024, pp. 500-514) Dopamine, a primary hormone and neurotransmitter, is central to reward-motivated behavior and learning by modulating striatal and prefrontal functions. (Wise, 2004) The human brain's reward system mediates the balance between impulsive limbic drives and goal-directed cortical motivations, thereby supporting flexible decision-making and adaptive motivational behaviors. (Yee, 2024).

Intrinsic and Extrinsic Processing in Learning and Meaning Construction

The environment provides more information than the brain can process, making survival dependent on effective saliency detection and attention management to guide perception and behavior. The brain continuously selects and prioritizes relevant input while suppressing irrelevant or distracting information. Information considered valuable or urgent for survival and well-being receives prioritized attention. Attention capacities, including alerting, orienting, and controlling attention, are regulated by multiple interacting brain systems. Top-down, cognitively driven attention, which supports goal-directed thinking, is associated with the dorsal attention network, comprising the intraparietal sulcus and the frontal eye fields. (Functional dissociation of the inferior frontal junction from the dorsal attention network in top-down attentional control, 2018) This mechanism enables engagement in activities such as reading, listening to lectures, considering questions, or composing written responses. In contrast, a second attention system operates in a bottom-up, stimulus-driven manner, orienting attention toward unexpected and behaviorally relevant stimuli. The ventral attention network, which includes the right temporoparietal junction and the ventral frontal cortex, facilitates rapid responses to urgent environmental demands, such as avoiding potential accidents. (Pedrazzini & Ptak, 2019) Flexible attention control depends on dynamic interactions and on switching between these two systems, a process that involves the central executive network (CEN). (Vossel et al., 2014)

Integrating Vygotsky's methods with contemporary brain science provides evidence-based strategies to enhance learning and teaching effectiveness.

1. Optimize the "Stretch Zone" (ZPD)

The Zone of Proximal Development (ZPD) refers to the range between tasks a student can complete independently and those achievable with guidance.

- Neuroplasticity is activated when students encounter tasks that are sufficiently challenging without being overwhelming. Such intellectual stimulation encourages the formation of new synaptic connections. (Tang et al., 2022)
- Teaching Action: Identify a student's baseline and provide just enough cognitive challenge to prevent both boredom and under-stimulation and excessive stress. is gradually removed as students master a task.
- Scaffolding reduces cognitive load and stress, thereby creating an environment that supports effective information processing and retention in the brain. (Doering & Veletsianos, 2007)
- Instructional strategies may include graphic organizers, stepwise templates, or collaborative group activities. As students develop procedural fluency and strengthen neural networks, these supports should be gradually withdrawn to promote independent performance.

2. Leverage Collaborative Learning

Vygotsky posited that learning is fundamentally social, occurring through interactions with peers and with individuals possessing greater expertise, such as teachers and subject-matter experts.

- Engagement in social interactions, conceptual discussions, and verbal explanations stimulates multiple brain regions, which in turn strengthens neural circuits. (Cacioppo & Berntson, 2002)
- Instructional approaches should emphasize peer discussions, collaborative problem-solving, and reciprocal teaching, wherein students' alternate roles as facilitators.

3. Encourage Language as a Tool for Thinking

Language functions as a critical cultural tool, enabling individuals to internalize knowledge and regulate cognitive processes. Verbalizing thoughts, including self-talk, facilitates the development and reinforcement of internal reasoning and problem-solving pathways within the brain. (Seligman & Reichenberg, 2009). Instructional strategies should promote activities such as thinking aloud, debating topics, writing reflective journals, and articulating thought processes, all of which contribute to the structural reorganization of neural pathways, enhancing comprehension. (Sáez et al., 2019). Comprehending these principles enables educators to design learning environments that not only facilitate education but also induce measurable changes in brain structure and function. (O'Neill, 2026).

Discussion and Conclusion

Historically, students were often required to choose between the humanities and the sciences. In recent years, however, integrative approaches have become increasingly prevalent within academic institutions. Multidisciplinary studies indicate positive effects on both learning and professional outcomes. (Zhang et al., 2024) Teaching neuroscience from both scientific and humanistic perspectives offers an innovative and effective means of bridging the gap between the humanities and the sciences. (Giraldez, 2020)

Explicitly connecting neuroscience, brain development, and behavior can significantly enhance students' academic and personal growth. (Goldberg, 2022) Applying scientific analysis to students' developmental experiences supports essential processes, including executive function, emotional regulation, metacognition, and social cognition. (Fleur et al., 2021)

Neuroscience offers insights into several critical topics relevant to adolescents and young adults, such as selective and leaky attention, the reward system and addiction, the prefrontal cortex–limbic developmental mismatch during adolescence, neurodiversity and inclusion, emotion regulation, and mental health. (Guirado et al., 2020)

Incorporating personal relevance into neuroscience education is essential for fostering student motivation. (Johansen et al., 2023) Teaching neuroscience from both scientific and personal perspectives and linking this knowledge to self-understanding enhances engagement and cultivates sustained interest in science. (Chang et al., 2021) This approach also facilitates the integration and transfer of scientific knowledge across various contexts. (Colvin, 2016) Similar to physical education, educational neuroscience raises awareness of brain health and encourages students to actively participate in their own development. Brain-friendly teaching applies principles that align with how the brain encodes, consolidates, and retrieves information. (Weinstein et al., 2018) Educational neuroscience emphasizes a holistic approach that integrates cognitive, emotional, and social factors to support learning and development. (Immordino-Yang, 2011) Maintaining physical health, cognitive challenge, and emotional safety is crucial for promoting neuroplasticity and effective learning. (Hötting & Röder, 2013)

Prioritizing learning progress over final outcomes encourages students to move beyond rote memorization and develop deeper, more enduring understanding. (Graaf et al., 2022) Instructional designs that promote experimentation, exploration, risk-taking, and opportunities to make mistakes without negative consequences for grades further support meaningful learning. (Lee, 2020)

Ongoing assessments that utilize multiple sample points and low-risk tasks provide valuable insights into students' learning trajectories. (Ecological cognitive assessment has incremental validity for predicting academic performance over and above single-occasion cognitive assessments, 2024) This approach enables the delivery of personalized, timely feedback that students can immediately apply to enhance their learning. (Cuéllar et al., 2025).

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