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# How Neuroscience Can Enhance Active Learning and Teaching in Practice: An Overview

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## Abstract

This article discusses that applying principles from neuroscience, specifically neuroplasticity, can significantly enhance active learning and teaching practices. By leveraging the brain's capacity for adaptive structural and functional changes, educators can promote deeper cognitive engagement with classroom learning outcomes. The extended human developmental period supports the acquisition of essential skills for complex brain maturation. Neuroscience provides educators with insights into learning mechanisms, supporting student achievement. This framework examines learning and memory neuroscience, focusing on how these processes can be leveraged in education. The article explores key concepts such as neuroscience in education, the brain's role in teaching and learning, neurodiversity and inclusive education practices, integrating neuroplasticity into curriculum content, and neuroeducational strategies for effective pedagogy. Ultimately, advances in understanding learning can foster new perspectives that actively engage students in their own education.

## Keywords

Neuroscience, Active Learning, Teaching, Learning Process, Student Support, Effective Pedagogy through Neuroscience

## 1. Introduction

Neuroscience and education are interdisciplinary domains that integrate cognitive psychology and educational theory to transform educational practices by applying insights from neuronal dynamics and brain plasticity. Adopting a neutral stance fosters critical thinking, increases student engagement, and improves knowledge retention. These fields collectively constitute the sciences of learning and teaching, providing a framework for understanding how environmental factors influence brain structure and function, thereby affecting learning outcomes. The discipline of mind, brain, and education investigates the reciprocal relationship between educational practices and brain function, examining how targeted interventions can enhance learning (Ansari et al., 2017).

Neuroscientific investigations of associative and reinforcement learning in both experimental animals and humans rely on a mechanistic, biological understanding of learning and memory. However, translating these findings into real-world educational settings remains limited. Education continues to face a tension between the objective of content transmission and the aim of cultivating skilled, independent thinkers and knowledgeable creators.

Educational neuroscience is grounded in the concept of neuroplasticity, the brain's capacity to reorganize and adapt in response to learning and experience. This theoretical framework supports the development of individualized learning strategies tailored to students' diverse needs. By applying neuroscientific insights into the roles of memory, attention, and emotion in cognitive processes, educators can design learning environments that foster both cognitive and social-emotional development (Howard-Jones et al., 2014; Nouri & Tokuhama, 2018).

Active learning requires students to engage directly with and manipulate course material. Pre-class preparation often consists of written summaries, quizzes, assigned problem sets, readings, or viewing pre-recorded lectures. In-class sessions typically emphasize discussion, application of content to real-world problems, problem-solving, quiz review, and project design. These activities enhance recall, information processing, metacognitive evaluation, and peer instruction. Mandating end-of-class summaries consolidates key concepts. Assessments are frequently embedded in daily activities as performance tasks, providing formative feedback to both students and instructors before or in place of summative assessments. Within active learning, students may initially struggle with content, undertake exploratory analysis of disciplinary material, and subsequently refine their understanding through in-class participation and feedback, thereby supporting metacognitive self-evaluation. The prevalence of daily challenges, collaborative work, and a collective sense of purpose increases motivation and decreases the likelihood of student disengagement. Instructional design and course structure are critical in facilitating activities that promote mastery of targeted knowledge and skills through practice, application, and error correction (Lombardi et al., 2021).

Academic instruction exhibits notable parallels with laboratory-based associative and reinforcement learning experiments, particularly those investigating naturalistic foraging behaviors in model organisms. In both settings, individuals operate within complex environments: students navigate intellectual material, while animals forage in physical space, both relying on similar neural mechanisms. Classroom learning necessitates the active construction and manipulation of mental models, which are analogous to the world-model representations that guide ecologically foraging decisions (Johnson et al., 2012; Metcalfe & Jacobs, 2010). The processes of learning, applying, and retaining concepts mirror an animal's navigation of its environment for survival, as both require mapping, exploration, and problem-solving in complex domains. For example, the rodent and human hippocampus support not only spatial navigation but also the organization and manipulation of abstract knowledge through comparable relational processes (Knudsen & Wallis, 2021; Theves et al., 2019). Furthermore, the motivational principles that drive effort toward goals in both academic and reward learning are fundamentally similar, as demonstrated by the allocation of effort to pursue either physical rewards or intellectual challenges (Vaidya & Badre, 2022; Westbrook et al., 2021).

## 2. Overview

Human development is shaped by genetic factors (nature), by environmental influences (nurture), and by their interactions. Epigenetic mechanisms play a role in this process (Weaver, 2014; Rangaswami, 2021). These factors are key to learning and to neuronal network reorganization. Such reorganization is the basis for the formation of new knowledge. Gaining knowledge or skills produces specific, repeated neural activity patterns. In Hebbian neuroplasticity, strong neural activity strengthens synapses. Fewer functional connections are eliminated (Kass & Jain, 2000; Cramer et al., 2011). About fifty years ago, Vygotsky introduced the concept of the zone of proximal development (ZPD) in educational theory (Vygotsky, 1980). The ZPD states that learning and development depend on a balance between support and challenge. This balance must fit each learner's developmental stage. This framework was transformative because it highlighted the importance of the educational environment (nurture) for realizing internal potential (nature). It also focused on the learning process, not just the learning product, as a primary educational goal (Vygotsky, 1980). Advances in the biology of learning have confirmed this perspective. They show that brain neuroplasticity is shaped by environmental conditions and by the balance between challenges and available supports (Davidson & McEwen, 2012). Stress impacts learning constructively or destructively, depending on its intensity, duration, accumulation, and the quality of available coping mechanisms and supports.

Educational neuroscience investigates the interconnections among physiological, cognitive, and behavioral dimensions of learning. Certain studies aim to identify optimal physical conditions for neuroplasticity and learning, such as the effects of sleep, physical exercise, and environmental pollution on brain function and cognitive performance (Thomas et al., 2019). While these studies examine the influence of brain health on learning, other research explores how learning itself impacts brain health, including the long-term effects of education on the brain and its relationship to healthier brain aging.

A subset of educational neuroscience research adopts a developmental perspective to investigate cognitive and learning capacities throughout the lifespan. For instance, studies utilizing multilevel data from adolescents—including neuronal, hormonal, psychological, and behavioral measures—have advanced understanding of how substantial neuronal changes during adolescence foster cognitive development while also heightening susceptibility to psychiatric disorders. Additional research examines factors that enhance neuroplasticity in the mature brain to support lifelong learning (Ho et al., 2011; Berryhill & Jones, 2012; Schneeweis et al., 2014).

Three educational practices common to all good pedagogy -spacing, novelty, and prior knowledge can be explained by synaptic plasticity. Educational psychologists advocate the use of learning and retrieval practices as pedagogical strategies to improve student performance (Agarwal & Roediger, 2018). Synaptic plasticity constitutes the central mechanism for learning and memory in the nervous system (Kandel et al., 2016; Schaefer et al., 2017). The central function of plasticity is to strengthen or weaken the cellular connectivity between communicating cells. Synaptic strengthening occurs both at the time of encoding and upon reactivation during memory recall, serving as the general mechanism for learning and remembering across timescales (Kandel et al., 2016; Schaefer et al., 2017).

### 2.1. Neuroscience in Education in Active Learning and Teaching Practice

Neuroscience research enables educators and specialists to better understand the diversity of cognitive processes and learning styles among students. These insights promote greater awareness and responsiveness to the needs of neurodivergent students—individuals whose brain functions differ from what is considered typical, such as those with ADHD, autism, dyslexia, and related conditions. Recognizing such differences allows educators to adapt instructional methods to more effectively accommodate and support diverse learners.

Recent years have seen growing interest in integrating brain science with educational practice. This trend has contributed to the emergence of educational neuroscience—a field that studies how the brain learns and how this knowledge can inform educational methods. It examines factors influencing learners' success or challenges in reading, numeracy, and writing (Ansari et al., 2012). Educational neuroscience offers foundational knowledge for teaching and learning by elucidating the neurobiological processes underlying learning and its development (Nouri & Tokuhama, 2018).

Educators are encouraged to create lessons that use analytical and logical reasoning. Cognitive challenges support brain function (Dubinsky et al., 2013). Research shows that repeated exposure to cognitive or sensory stimuli makes neural connections stronger (Caroni et al., 2012).

### 2.2. Neuroscience: The Brain's Role in Learning and Teaching Practice

Neuroscience is an interdisciplinary field dedicated to the study of the brain and nervous system. In this context, learning is conceptualized as a process involving synaptic reorganization, neuronal circuits, and interconnected neural networks (Lent, 2019). Neuroscience provides a framework for investigating the mechanisms underlying emotional, behavioral, and cognitive processes that explain how the brain acquires knowledge. Importantly, neuroscience research has demonstrated the brain's capacity for continual change, as individual neurons adapt during learning (Fillenze & Morris, 2003). This process, termed neuroplasticity, refers to the rewiring and strengthening of connections between neurons (Cunnington, 2019).

Neuroscience informs educational philosophies by emphasizing student engagement, emotional well-being, and supportive learning environments. Educators and scientists collaborate to clarify the brain's role in motivation and emotional regulation, advancing more effective teaching practices. A deeper understanding of neuroscience enables educators to design lessons that address students' specific needs. Research suggests that teachers can better support students across disciplines by expanding their knowledge of brain function. Recognizing that the brain undergoes physical changes and that neural connections strengthen through practice allows educators to foster student motivation and reinforce the idea that intelligence is malleable.

### 2.3. Neurodiversity and Inclusive Education Practices for Teachers and Learners

Ongoing advances in neuroscience illuminate the brain's complexities and fuel educational innovation. This paragraph argues that neuroeducation offers educators a unique opportunity: integrating neuroscience with pedagogy enables them to create more engaging and effective learning experiences. This interdisciplinary approach empowers teachers to enhance learning environments by directly applying neuroscientific insights to instructional methods (Ansari et al., 2012; Owens & Tanner, 2017; Dubinsky et al., 2013).

For learners with limited working memory, implement simple tasks that facilitate long-term retention. For instance, instruct students to write a one-minute summary of what they recall immediately following an activity or lesson. Peer teaching, in which students collaborate in pairs, can further reinforce lesson content. Fostering learners' curiosity can motivate exploration and deeper understanding of their environment. Encourage students to use sensory information to gather data and apply it to problem-solving or prediction tasks. Decompose complex assignments into smaller, manageable steps and monitor progress to prevent students from becoming overwhelmed. Require students to document completion using rubrics, recordings, peer assessments, or similar methods. Offer feedback and share exemplars at each stage to support ongoing progress.

### 2.4. Using Neuroplasticity as Educational Content

The science of human motivation, particularly the concept of evolutionary mismatch, offers valuable insight into the challenges students face regarding learning motivation. This theoretical framework allows for the assessment of students' tendencies to approach or avoid learning challenges. An understanding of the neuroscience underlying motivation and reward can help students recognize and regulate their reward systems. Adolescence is a critical developmental period during which substance use often begins, and early initiation is linked to an increased risk of persistent mental health or substance use disorders in adulthood (Degenhardt et al., 2016; Poudel & Gautam, 2017; Trujillo et al., 2019). Comprehending the relationship between the reward system and brain development is crucial for educators, as it can inform evidence-based strategies to prevent and reduce the risk of adolescent addiction.

### 2.5. Neuroscience Mechanisms of Active Learning and Teaching Practice

Neuroscience offers important insights into the mechanisms underlying learning, informing educators and students alike. The human brain comprises over 100 billion neurons, each forming connections with more than 1000 other neurons. This extensive network creates a vast array of synaptic connections, which supports substantial learning potential. Engaging multiple senses in personally meaningful tasks strengthens neural connections and facilitates the formation of long-term memories. Instruction can be improved by implementing active, meaningful, and multisensory teaching strategies, as these methods reinforce neural connectivity.

Active learning improves brain function by increasing cerebral blood flow, promoting neurotransmitter release, and supporting synaptic plasticity, thereby enhancing memory and engagement compared to passive instructional methods. Collaborative activities, physical movement, and problem-solving tasks stimulate neural networks and reduce stress-induced cortisol levels, a hormone that can hinder learning. Engagement through discussion, problem-solving, and collaboration further optimizes neural plasticity, stimulates dopamine release, and strengthens neural pathways associated with long-term memory. Effective instructional practices that facilitate these processes include creating a supportive, low-stress environment, employing spaced repetition, providing immediate feedback, and incorporating multisensory and novel teaching methods to maintain attention and improve retention.

### 2.6. Using Neuroplasticity to Guide Active Learning Design for Teaching

Structuring learning systems to foster conditions that support neuroplasticity can substantially enhance both academic development and overall well-being among learners. Educational environments that promote neuroplasticity should model and encourage healthy lifestyle practices, such as regular physical activity, balanced nutrition, sufficient sleep, and effective stress management. For example, educating students about the negative effects of sleep deprivation on learning outcomes is crucial. In addition, learning systems should emphasize intellectual stimulation through exposure to novelty and challenge, while also cultivating a positive social and emotional climate defined by strong interpersonal connections.

Neuroplasticity and developmental progress are optimized when learners engage within the stretch zone, which offers an ideal balance of challenge and emotional support in a socially secure setting. Equipping educators with knowledge about neuroplasticity is essential for enabling them to understand and support students who have experienced trauma. Childhood adversity impairs neuroplasticity in both duration and magnitude (McLaughlin et al., 2014); a brain oriented toward survival is not conducive to learning. While early trauma compromises neuroplasticity, it can also facilitate recovery. Schools play a vital role in mitigating the effects of early trauma by establishing enriched and safe learning environments that reinforce alternative neuronal pathways, thereby counteracting the adverse impact of early negative experiences on child development (Bryck & Fisher, 2012).

### 2.7. Neuroeducational Strategies for Effective Pedagogy for Teaching and Learning

Various pedagogical techniques have been developed and implemented to enhance student engagement, collaboration, and the learning process. Emplacing the foundation of neuroeducation practices, the think-pair-share activity serves the ultimate purposes of encoding memories within synaptic connections and neural circuits. This process has altered the connections between neurons in students' brains, enabling them to recall the solution to the task months later and potentially for the rest of their lives (Owens & Tanner, 2017).

Peer teaching is a pedagogical method in which students instruct classmates on concepts or problem-solving techniques, thereby strengthening their understanding and fostering teamwork and knowledge exchange (Polkowski et al., 2020). This method deepens comprehension, improves communication, and incorporates diverse perspectives. By utilizing social interactions, such as discussion-based learning, students enhance retention and align with research supporting social learning environments as crucial for brain plasticity.

The Jigsaw technique divides students into small groups, each specializing in a topic, and then has them share their expertise with the class (Clark & Dumas, 2015; Cochon Drouet et al., 2023). This structure amplifies peer learning and active engagement (Owens & Tanner, 2017; Nathaniel et al., 2018). Round-robin brainstorming ensures equitable participation and fosters inclusivity. These methods collectively develop students' understanding, presentation, and communication skills, supporting the primary claim that collaboration enhances learning in academic and professional contexts.

Educational neuroscience leverages diverse stimuli, including brain stimulation techniques, to improve learning. Studies focusing on transcranial electrical stimulation have shown effects on cognitive functions and arithmetic learning, suggesting that innovative methods can support the main argument that social and scientific approaches together enhance educational outcomes.

This structured strategy facilitates active participation and idea generation by having students take turns contributing (Aini, 2023a, 2023b). These techniques promote engagement and critical thinking, synthesizing diverse viewpoints through collaboration. By deepening understanding and developing problem-solving skills, this approach advances curriculum development in developing countries and strengthens the main argument about the value of collaborative and modern educational strategies.

## 3. Discussion and Conclusion

Classrooms that utilize neuroscience-based methods enable educators to tailor instruction to individual learning needs. The integration of neuroscience, education, artificial intelligence, and machine learning facilitates genuinely personalized learning experiences. Lessons informed by brain development foster academic growth, stimulate critical thinking, and promote personal discovery. Guided by educational neuroscience, teachers combine scientific understanding with pedagogical strategies to cultivate lifelong curiosity. Providing students with diverse opportunities to demonstrate their learning enhances memory retention and builds confidence. Creative practice and authentic problem-solving transform new concepts into enduring knowledge. Educators who implement these principles establish learning environments where all students can succeed, supporting both academic achievement and personal development.

Implementing brain-compatible instructional strategies requires educators to apply principles that reflect the brain's processes of encoding, consolidation, and retrieval. Educational neuroscience advocates for a holistic approach that integrates cognitive, emotional, and social dimensions to optimize learning and development (Immordino-Yang, Darling-Hammond, & Krone, 2018; Meltzoff et al., 2009; Chen & Kalyuga, 2020). Supporting physical well-being, engaging cognitive processes, and ensuring emotional security contribute to enriched environments that promote neuroplasticity and effective learning. Prioritizing ongoing assessment of learning progress, rather than focusing solely on final outcomes, encourages students to move beyond rote memorization and achieve a deeper understanding. Instructional designs that foster experimentation, exploration, and risk-taking, and that permit learning from mistakes without punitive grading, facilitate meaningful learning experiences. Ongoing formative assessments utilizing multiple data sources and low-stakes tasks provide valuable insights into student learning and enable educators to deliver timely, personalized feedback that supports continuous improvement. For instance, classroom studies have demonstrated that students who participated in weekly low-stakes quizzes increased retention by 20 percent, illustrating the benefits of frequent formative assessment. Teaching students about their developing brains enhances both academic and personal growth, expands cognitive capacity, and strengthens self-identity. Educational neuroscience offers educators promising strategies to teach students about their brains and to apply brain-compatible instructional methods that support lifelong learning.

Neuroscientific research indicates that active learning engages students, elicits emotional responses, and promotes social interaction, thereby enhancing synaptic plasticity. Despite these benefits, persistent neuromyths, limited translation of laboratory research to classroom practice, and practical constraints such as time, resources, and classroom management present significant challenges for educators. Active learning enhances retention by activating reinforcement circuits, yet effective implementation requires addressing these obstacles. When educators stimulate the reinforcement learning circuit and foster agency, curiosity, and peer-to-peer interaction, they increase motivation, retention, and higher-order thinking skills within active learning environments. Additionally, engaging the reinforcement learning circuit during periods of working memory overload further improves retention, offering a mechanistic explanation for the effectiveness of active learning. This analysis outlines how emerging neuroscience principles can inform educate following practical recommendations are advised for educators: 1) participate in professional development focused on the principles of the nervous system to understand the neurophysiological foundations of effective instructional methods; 2) implement all four identified neurostrategies in classroom practice, maintaining balance among these strategies; and 3) encourage all students, regardless of academic achievement, to utilize evidence-based learning strategies that foster autonomy, confidence, and active engagement. Continued research integrating education, psychology, and neuroscience is essential for advancing educational practice. Longitudinal studies should be conducted to support individual student learning success and to enhance overall educational outcomes. Individual student learning success and enhancing educational outcomes.

## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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