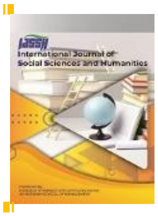

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Neurological Biology and Its Relation to Education: Implications of Neuroscience For Learning Practice in the 21st Century

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Abstract

This study examines the relationship between neurobiology (neuroscience) and modern educational practices. Advances in neuroscience over the past two decades have opened new insights into how the human brain learns, stores memory, and processes information. This review aims to: (1) describe the neurobiological mechanisms underlying the learning process; (2) identify the implications of neuroscience findings on learning strategies; and (3) formulate evidence-based recommendations for educators. A systematic literature review of 45 articles published between 2010-2024 from Scopus, Web of Science, and Google Scholar databases was conducted. Results indicate that neuroplasticity, the role of emotions in memory consolidation, and sleep cycles have direct relevance to learning effectiveness. Neuroscience-based learning strategies such as spaced repetition, retrieval practice, and multimodal learning are proven to enhance long-term knowledge retention. These findings affirm the need to integrate neuroscience knowledge into teacher training curricula and instructional design.

Contents

Introduction

Neurological biology or neuroscience is a branch of science that studies the nervous systems of living things, ranging from the molecular level to behavior and cognition. In the last two decades,

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neuroscience findings have made significant contributions to our understanding of how humans learn (Goswami, 2015). The development of brain imaging technologies such as FMRI (*Functional Magnetic Resonance Imaging*) and EEG (*Electroencephalography*) allows scientists to observe brain activity directly during the learning process (Dehaene, 2020). The integration of neuroscience into the world of education gave birth to a new discipline known as *educational neuroscience* or neuroeducation. This field seeks to bridge the gap between scientific findings in the laboratory and real practice in the classroom (Howard-Jones, 2014). Nonetheless, many educators have not fully understood or utilized neuroscience findings in their teaching practices. A survey conducted by Pashler et al. (2008) shows that a number of myths about the brain are still widespread among teachers, such as the myth of visual-auditory-kinesthetic learning styles that do not have a strong scientific basis.

In Indonesia, attention to educational neuroscience is still relatively limited. Local studies show that teachers' understanding of how the brain works in learning is still minimal, so the learning strategies applied are not always in line with how the brain optimally processes information (Suryana & Mulyana, 2021). In fact, a proper understanding of learning neurobiology can be the foundation for designing more effective curriculum and teaching methods. Based on this background, this article aims to: (1) describe the neurobiological mechanisms underlying the human learning process; (2) identify the implications of neuroscience findings on learning strategies and methods; and (3) formulate evidence-based practical recommendations for educators in Indonesia. This study is expected to enrich scientific insights and make a real contribution to improving the quality of national education.

Methods

This study uses a systematic literature review method which refers to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Moher et al., 2009). The literature search was conducted through three scientific databases, namely Scopus, Web of Science, and Google Scholar with a publication time range from 2010 to 2024. Keywords used in the search included: neuroscience and education, neuroplasticity learning, brain-based learning, memory consolidation education, and educational neuroscience Indonesia. Article inclusion criteria include: (1) published in an indexed journal; (2) speak Indonesian or English; (3) discuss neuroscience in the context of education; and (4) is an empirical research article, review, or case study. Articles that are opinion pieces without empirical data support are excluded. Of the total 312 articles found, 267 articles were eliminated based on irrelevant titles and abstracts, leaving 45 articles that were analyzed in depth. The analysis was conducted using a thematic approach (Braun & Clarke, 2006) to identify key themes related to the relationship between neuroscience and education.

Results and Discussions

The learning process at the biological level involves structural and functional changes in the brain. The basic unit of information processing in the nervous system is neurons, which communicate with each other through synapses. When a person learns something new, there is a strengthening of synaptic connections between neurons through a mechanism known as *Long-Term Potentiation* (LTP) (Bliss & Lømo, 1973; Kandel et al., 2014). Hebb's principle *of 'cells that fire together, wire together'* describes this phenomenon accurately: the more often two neurons are active simultaneously, the stronger the connection between them.

Neuroplasticity is the brain's ability to change and adapt throughout life is the biological foundation of learning (Doidge, 2007). The finding that neuroplasticity does not only occur in childhood (critical period) but lasts throughout life carries important implications: even the adult human brain is still able to form new neural connections and modify existing ones. Draganski et al. (2004) demonstrated this through an experiment in which students who learned to juggle for three months showed an increase in the volume of *grey matter* in areas of the cortex involved in visual and motor processing.

In addition to LTP, memory consolidation also involves processes at the molecular level, including the synthesis of new proteins and changes in gene expression (Alberini & Ledoux, 2013). The hippocampus, a structure located in the medial temporal lobe, plays a crucial role in the formation of declarative memory (facts and events), while the basal ganglia play more role in the formation of procedural or habitual memory (Squire & Dede, 2015).

1. The Role of Emotions in Learning

Neuroscience has uncovered a close link between emotions and cognition in the learning process. The amygdala, an almond-shaped structure in the brain, plays a central role in the processing of emotions and is known to have a direct connection with the hippocampus (LeDoux, 2015). Neuroimaging research shows that stimuli that have a strong emotional charge tend to be processed more deeply and remembered longer than those that are neutral (Cahill & McGaugh, 1998).

Chronic stress brought on by an unsafe or stressful learning environment can impair hippocampal function and inhibit memory consolidation. The stress hormone cortisol in high levels has been shown to interfere with information processing in the prefrontal cortex, the area responsible for executive functions such as planning, problem-solving, and self-regulation (Arnsten, 2015). Conversely, a positive, supportive, and affectionate-rich learning environment encourages the release of dopamine and serotonin which facilitates focus, motivation, and memory consolidation (Willis, 2007).

The pedagogical implications of these findings are clear: teachers need to create an emotionally safe classroom environment. Immordino-Yang & Damasio (2007) argue that emotions are not just a disruption to cognition, but rather an essential component of rational thinking and decision-making processes. Therefore, an educational approach that ignores the affective dimension of students is not in line with the findings of cutting-edge neuroscience.

2. Sleep, Naps, and Memory Consolidation

One of the most revolutionary findings in cognitive neuroscience is the role of sleep in memory consolidation. During sleep, especially in the phases of slow-wave sleep (SWS) and REM (Rapid Eye Movement) sleep, the brain actively repeats and integrates new information with existing knowledge (Walker, 2017). This memory replay process strengthens the memory footprint and transfers information from temporary storage (hippocampus) to long-term storage (neocortex) (Stickgold, 2005).

Research involving college students shows that studying all nighter before an exam is counterproductive because it deprives the brain of the opportunity to consolidate memory (Diekelmann & Born, 2010). Even short naps of 20-90 minutes after learning have been shown to significantly improve information retention compared to staying awake (Mednick et al., 2003). These findings have direct implications for the scheduling of teaching and learning activities and school hours policies.

3. Neuroscience-Based Learning Strategies

Based on neuroscience findings, several learning strategies have been proven to be scientifically effective and applicable in classroom settings. One of the most widely supported strategies is spaced repetition. Ebbinghaus' forgetting curve explains that information decays rapidly when it is not reviewed. Cepeda et al. (2006) further confirmed that revising learning material at increasing time intervals significantly improves long-term retention compared to massed practice. This principle is now widely implemented in digital learning applications such as Anki and Quizlet, which use algorithms to optimise review timing. Another effective strategy is retrieval practice. This approach involves actively recalling information through self-testing or answering questions rather than passively rereading material. Roediger and Karpicke (2006) found that retrieval practice produces stronger and more durable learning outcomes than re-exposure to content. From a neuroscience perspective, repeated retrieval strengthens neural pathways associated with memory access, making information easier to recall in the future.

Multimodal learning also plays an important role in enhancing cognitive processing. According to Mayer (2009), learning is more effective when information is presented using both verbal and visual channels compared to verbal input alone. Engaging multiple sensory modalities activates different areas of the brain simultaneously, thereby creating more retrieval cues and improving understanding and memory consolidation. In addition to instructional strategies, the learning environment significantly influences cognitive performance. Jensen (2008) highlights that adequate lighting, comfortable room temperature (approximately 18–21°C), and reduced cognitive distractions support optimal functioning of the prefrontal cortex. Furthermore, Cotman and Berchtold (2002) found that light physical activity, such as walking, increases Brain-Derived Neurotrophic Factor (BDNF), a key protein that supports neuronal growth, survival, and synaptic plasticity, thereby enhancing overall learning capacity.

4. Neuromyths in Education

In addition to valid neuroscience findings, the field of education is still influenced by various neuroscience myths or neuromyths that have been scientifically refuted but continue to circulate among educators. These misconceptions may lead to inaccurate instructional decisions and reduce the effectiveness of evidence-based learning practices. Several studies have shown that neuromyths remain persistent in educational settings despite the availability of scientific evidence that contradicts them (OECD, 2002; Dekker et al., 2012).

One common neuromyth is the belief that humans use only 10% of their brain capacity. This claim is scientifically inaccurate because brain imaging studies show that almost all brain areas are active across different types of activities, although the level of activation varies depending on the task performed (Herculano-Houzel, 2002). Another widespread misconception is the VAK learning style myth, which assumes that students learn better when teaching methods are matched to visual, auditory, or kinaesthetic preferences. However, Pashler et al. (2008) found no strong evidence that adapting instruction to these learning styles significantly improves learning outcomes.

A further neuromyth concerns left-brain and right-brain dominance. Although certain cognitive functions show hemispheric specialisation, this does not mean that individuals predominantly use one side of the brain for all thinking processes. Nielsen et al. (2013) demonstrated that brain functions involve complex networks across both hemispheres. Therefore, the spread of neuromyths among educators can hinder the implementation of scientifically grounded teaching strategies. For this reason, neuroscience literacy should become an essential component of teacher education and professional development programmes to support more accurate, effective, and evidence-based learning practices (Torrijos-Muelas et al., 2021).

5. Implications for Indonesia's Education Policy

Based on the above findings, several policy implications can be formulated for the Indonesian education context. First, the Independent Curriculum that encourages project-based learning and differentiation is in line with neuroscience principles that emphasize active involvement and meaningful context for the brain (Suryana & Mulyana, 2021). Second, the Teacher Professional Education (PPG) program needs to include an educational neuroscience module so that prospective teachers have a scientific understanding of the learning process.

Third, school hours policies that consider the circadian rhythms of students, especially adolescents who biologically have a slower sleep phase, can improve cognitive performance and mental health (Carskadon, 2011). Fourth, mental health programs in schools that pay attention to the neurochemical aspects of stress can create a more neurologically conducive learning environment.

Conclusion

Neural biology provides a powerful scientific framework for understanding why and how humans learn. Neuroplasticity proves that the brain is dynamic and can be changed through proper learning experiences. Emotions, sleep, and the physical-psychological environment have a neurobiological basis that cannot be ignored in designing effective learning. The findings of this study indicate that strategies such as *spaced repetition, retrieval practice*, and multimodal learning have strong neuroscience support and should be integrated into daily teaching practices. Instead, educators need to avoid neuromyths that are not supported by scientific evidence. An accurate understanding of neural biology is not just the domain of scientists, but a crucial professional skill for every educator in the 21st century. Further research is needed, especially empirical studies that explore the application of neuroscience principles in the Indonesian classroom by considering specific cultural and socio-economic contexts. Interdisciplinary collaboration between neuroscientists, educational psychologists, and pedagogical practitioners is the key to realizing evidence-based education in Indonesia.

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