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NEURODIDACTIC APPROACHES IN TEACHING NATURAL SCIENCES: THE RELATIONSHIP BETWEEN COGNITIVE PROCESSES AND LEARNING OUTCOMES

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Abstract. *This article investigates the implementation of neurodidactic approaches in natural science education and analyses how key cognitive processes—attention, working memory, perception, and long-term memory—affect learning outcomes. Integrating neuroscience-based teaching strategies is considered essential in the context of increasingly complex STEM curricula. A pilot experimental study involving 48 secondary school students was conducted to evaluate the effectiveness of neurodidactic instruction compared to traditional methods. Results show significant improvements in conceptual understanding, attention stability, memory retention, and motivation among students taught with neurodidactic strategies. The study concludes with a proposed model for integrating neurodidactic principles into science classrooms and discusses implications for future research.*

Keywords: *neurodidactics, cognitive processes, STEM education, attention regulation, cognitive load, memory retention, neuroscience-based pedagogy.*

1. Introduction. The rapid evolution of educational neuroscience has created opportunities to redesign instructional methods in natural science education. Traditional teaching approaches often overlook how the human brain processes, stores, and retrieves information.

Neurodidactics—an interdisciplinary field combining neuroscience, psychology, and pedagogy—seeks to align teaching with the brain's cognitive mechanisms to improve learning outcomes. Scholars such as Jensen (2020), Spitzer (2019), and Medina (2014) emphasize that effective learning occurs when instruction supports attention, reduces cognitive overload, and facilitates memory consolidation.

Natural sciences (biology, chemistry, physics) require students to interpret abstract concepts, visualize complex systems, and engage in logical reasoning. These tasks rely heavily on cognitive functions such as selective attention, working memory capacity, and perceptual processing. Given these demands, neurodidactic principles can play a critical role in optimizing instructional strategies for STEM subjects.

This article examines theoretical foundations of neurodidactic approaches and presents the results of a small-scale experiment investigating their impact on learning outcomes in natural science education.

2. Literature Review

2.1 Neurodidactics as a Pedagogical Discipline

Neurodidactics emerged in the 1990s through the works of Holodynski and Spitzer. The discipline is grounded in findings on synaptic plasticity, neural networks, and the role of emotions in learning. Core principles include:

- learning is strengthened when attention is actively guided;
- reducing extraneous cognitive load enhances comprehension;

- multimodal stimuli support deeper information processing;
- spaced repetition and retrieval practice improve long-term memory.

2.2 Cognitive Processes in Natural Science Learning

STEM learning requires the integration of multiple cognitive operations:

- **Selective attention** enables students to filter experimental data and relevant information.
- **Working memory** supports the manipulation of formulas, models, and logical relationships.
- **Long-term memory** allows storage of scientific laws and conceptual frameworks.
- **Perception** contributes to understanding diagrams, micrographs, and visual models.

Studies by Gardner (2021) and Cozolino (2013) suggest that improved cognitive flexibility enhances problem-solving in scientific contexts.

2.3 International Neurodidactic Practices in STEM

Countries such as Finland, Germany, Japan, and South Korea have incorporated neurodidactic insights into national curricula. These practices include:

- inquiry-based neurodidactic activities;
- concept mapping to manage cognitive load;
- emotion-rich contextual learning;
- multimodal visualization tools and digital simulations.

These international experiences demonstrate strong potential for improving student engagement and performance.

3. Methodology.A qualitative and quantitative mixed-method design was used. The conceptual analysis is based on scholarly publications (2015–2024) on educational neuroscience, cognitive psychology, and STEM pedagogy. Additionally, a **pilot experimental study** was conducted to evaluate the real impact of neurodidactic teaching in a natural science classroom.

Participants. 48 students aged 14–15 from a secondary school participated. They were randomly assigned into:

- **Experimental Group (EG)** – 24 students
- **Control Group (CG)** – 24 students

Procedure. The study lasted **two weeks (8 academic hours)** and covered topics in cell biology and basic physics. Both groups completed pre-tests and post-tests; EG received instruction based on neurodidactic strategies, while CG was taught through traditional lecturing.

Neurodidactic Interventions Applied in EG

1. Attention-guiding cues (visual signaling, questioning techniques)
2. Chunking and reduction of extraneous cognitive load
3. Multimodal learning (3D models, videos, simulations)
4. Spaced repetition and retrieval practice
5. Emotionally engaging examples and real-life phenomena

Data were analyzed using descriptive statistics and qualitative observation.

4. Results

4.1 Quantitative Findings

Pre-test Results

- EG: **9.1 / 15**

- CG: **9.3 / 15**

No significant difference ($p > 0.05$).

Post-test Results

- EG: **13.4 / 15**
- CG: **11.2 / 15**

Statistically significant improvement ($p < 0.01$).

Learning Gains

- EG improvement: **+4.3**
- CG improvement: **+1.9**

The experimental group improved **2.26 times more** than the control group.

Delayed Retention Test (after 1 week)

- EG retention: **87%**
- CG retention: **64%**

These results indicate that neurodidactic instruction significantly improves both immediate understanding and long-term memory consolidation.

4.2 Qualitative Findings

Classroom observation revealed:

1. **Attention Stability:** EG students maintained focus longer; their average attention span increased compared to CG.
2. **Cognitive Load Reduction:** Students in EG reported higher clarity and reduced confusion due to structured and simplified content presentation.
3. **Higher Motivation:** EG students showed greater engagement in hands-on tasks and discussions.
4. **Better Conceptual Integration:** EG students made more interdisciplinary connections, such as linking cell processes with physics concepts.

5. Discussion. The pilot experiment demonstrates the strong impact of neurodidactic principles on natural science learning. Cognitive processes play a crucial mediating role:

- **Attention-driven learning** ensures that relevant information is encoded effectively.
- **Working memory limitations** are managed through chunking and reduced cognitive load.
- **Long-term memory** benefits from retrieval practice and spaced repetition.
- **Emotional engagement** supports neural consolidation via dopamine activation.

The findings align with Spitzer (2019), Jensen (2020), and Sweller's Cognitive Load Theory (2011). The neurodidactic interventions enabled students to process scientific information more efficiently, resulting in higher performance and motivation.

6. Conclusion. The study confirms that neurodidactic approaches significantly enhance learning outcomes in natural sciences by supporting cognitive processes essential for scientific understanding. Compared to traditional instruction, neurodidactic teaching:

- increases attention stability,
- minimizes cognitive overload,
- improves memory retention,
- enhances conceptual reasoning,
- raises student motivation.

Although the experiment was small-scale, results support a broader integration of neurodidactic strategies into STEM education. Future studies should include larger samples, more variables, and comparative analysis across different grade levels and science disciplines.

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