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Educational Neuroscience and its Contribution to Math Learning

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Abstract. In recent decades, an increasing number of educators have focused on neuroscience to investigate how learning experiences shape the brains and cognitive development of young people. This work seeks to capture the functions of the brain and education within this setting. The goal of educational neuroscience is to expand and integrate the existing knowledge about the biological bases of learning from neuroscience in education. Educational neuroscience focuses on enhancing the learning process using brain-related discoveries. The significance of this investigation is in determining whether educational neuroscience may achieve a redefining of knowledge about mathematics education and learning and how this knowledge can be applied in educational practice.

Keywords: Neuroscience, Educational Neuroscience, Math Learning, Cognitive Development

1. Introduction

Neuroscience is an interdisciplinary field that focuses on the study of the nervous system's anatomy, physiology, and functionality, as well as its effects on human development, health, and behavior. It has become possible to investigate in vivo the complex interactions regarding the structure and function of the brain, both against normal subjects and those distinguished by significant disorders, as a result of the significant advancements that have occurred in the medical field as well as in the field of computing technology over the past decade. Consequently, using methods based on electrophysiological and neuroimaging tests and studies can provide experimental results that cannot be determined through behavioral investigation. Educational neuroscience is an interdisciplinary field in which researchers from a variety of scientific fields collaborate with educators of all specializations and levels to identify methods and techniques to enhance and advance the learning process. With the aid of neuroscience's methodological tools, the innovative, inter-disciplinary field examines and attempts to resolve issues related to education and the learning process. Cognitive Neuroscience is primarily concerned with the cognitive subject of mathematics learning. Cognitive Science and Neuroscience seek to improve mathematics through the application of mind science to human mathematical concepts.

2. Literature Review

Several Neuroscientific studies have demonstrated the consolidation of brain structure and function. Significant advances in neuroscience research have yielded novel approaches, which in turn provide the

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framework for comprehending brain functions, with decisive implications for teaching and learning. The new field of neuroscience, cognitive neuroscience, investigates some of the fundamental processes associated with the learning process and metacognition, cognitive control and flexibility, as well as the individual's social and emotional experience. The learning process is a complicated function that affects educational standing; therefore, the interdisciplinary approach of educational neuroscience is timely and practical. Given its role in all of an individual's mental, emotional, and motor functions, the brain is the preeminent "organ of learning." The brain is composed of approximately 100 billion neurons connected by synapses, which are discontinuous contacts.

By imaging the functional changes that the brain undergoes over time, including both normal and pathological mental activity, it is possible to directly examine more complex cognitive processes. Cognitive neuroimaging methods are the methodological instrument of the sciences for investigating and studying particular cognitive processes. In addition, the results of the last decade of neuroscientific research have significantly clarified the determining functions associated with the development of capabilities in specialized fields of learning, such as language acquisition and reading and arithmetic skills. Educational neuroscience focuses on expanding and analyzing the unknowns that characterize the biological processes that support learning via neuroscience and genetics. The ultimate objective of educational neuroscience is to comprehend the biological mechanisms that relate to learning abilities and difficulties and to aid teachers and parents in fostering the individual learning and development of children.

Educational neuroscience is a multidisciplinary field primarily comprised of neuroscientists, educators, and researchers who implement a standard design without involving themselves with theories, methodological practices, or policies. Almost every expert performs his duties. It would be irresponsible not to mention that when treated as an interdisciplinary activity, the expected result was for neuroscientists and educators to actively accept each other's theories in an effort to jointly improve their contributions to a specialized project (Anderson & Della Sala, 2012). Lastly, if it is handled as an interdisciplinary activity, an idea also embraced by Campbell (2010), it must entail the adoption of new philosophical frameworks and methodological tools to ensure the union between the various ways of education with neuroscience, of mind and brain, and the objective and the subjective.

Campbell (2010) conceives of the mind as a lived experience from a philosophical standpoint. Essentially, the mind and the material coexist. Considered necessary is that the mind does affect matter, which implies that a necessary condition is that one's mind can, at least to some extent, have causal effects on others, including his brain and body. Examining the preceding, it is discovered that such an approach contradicts the fundamental philosophical commitments of the majority of scientists, namely the notion that the mind cannot possess causal efficacy. If an alternative assumption existed, it would be necessary to eliminate the will as a human characteristic in order to make the experience a function of the environment. It examines mind and brain as distinct aspects of a single "brain-mind," thereby establishing educational neuroscience as a valid field of study.

If the desire to study subjective empirical changes in the trainees' mental states is pursued, the study of brain and brain behavior may be of assistance. This is the reason for the scientific study of psychophysiology and cognitive neuroscience. Consequently, educational neuroscience can bring methodological tools and theories and share results with these disciplines without invoking philosophical considerations. In addition, the specific perspective that pertains to educational neuroscience in a broad sense seeks to bridge the gap between mind and body by focusing on the brain

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as the organ of thought. Thus, the nature and various effects of the educational experience can be comprehended (Anderson & Della Sala, 2012). Neuroscience is an interdisciplinary field that investigates the anatomy, physiology, and functionality of the nervous system and its effects on development, health, and behavior.

To clarify the relationship between brain function and the learning process, the crucial role of neurons must be highlighted. Our brain is comprised of approximately 85 billion neurons that are interconnected and related through synapses and carry the information required to perform a variety of functions. Cognitive functions, i.e., the mental processes associated with information consolidation and retention, are directly dependent on hippocampus function (Kesner, 1998). The hippocampus is the region of the brain responsible for transferring information from short-term to long-term memory, which affects spatial navigation (Ito, 2004). At the same time, there are cognitive functions such as the ability to connect information, make decisions, evaluate and analyze information; these functions are linked to regions in the cerebral cortex (Howard-Jones, 2014).

Regarding educational neuroscience's effects, the following should be mentioned: The application of educational neuroscience contributes to the transformation and development of education through the creation of innovative structures that facilitate the transformation of teaching work and the learning process based on the findings of neuroscience research (Antonopoulou et al., 2021d; Antonopoulou et al., 2022). This fact represents a novel approach to educational science (Gkintoni et al., 2021a). Specifically, the initial effects of educational neuroscience consist of removing the conclusion and conventional approach that children's learning performance is solely determined by environmental factors. Biological factors play a crucial role in the differences in learning abilities among individuals (Gkintoni & Dimakos, 2022; Gkintoni et al., 2021c). The study of biological causes has made research on the consolidation of fundamental learning difficulties, dyslexia being the most prevalent example, safe and practical (Nouri, 2016).

In addition, educational neuroscience has revealed that the brain continues to differentiate as a consequence of the learning process. Despite continuous change, the human lifespan is still characterized as "plastic." The dimensions of this discovery can be understood in terms of individual decisions regarding lifelong learning and the continuous acquisition of new skills and knowledge (Antonopoulou et al., 2019; 2020; 2021a; 2021b; 2021c). In addition, it should be emphasized that learning is not exclusively a mental process. It is a complex process that depends on a person's existing knowledge, motivation, environmental factors, interests, and psychological, spiritual, and physical health; it has a catalytic effect and enhances the quality of life (Tzanos et al ., 2019). There is no longer the outmoded assumption that the student will passively and uncritically accept the information imparted by the teacher (Hardiman et al., 2012).

Additionally, educational neuroscience's contribution to the issue of emotion and learning is decisive. Prior to the modern era, the approach to education emphasized mental functions while ignoring the emotional aspect of the individual. For instance, based on research in neurosciences, secondary art courses in the school curriculum are characterized as aiding the functioning of the individual's brain and contributing significantly to their emotional acuity. In addition, it should be noted that stress and traumatic events (Gkintoni et al., 2022a; Gkintoni et al., 2021b) cause changes in the neurons of the brain, which negatively affect the learning process.

3. Methodology

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This specific metadata review on the topic of educational neuroscience attempts to answer the following research questions:

- [RQ1] How is Educational Neuroscience conceptually and philosophically established?
- [RQ2] What motivations, methodologies, and effects does Educational Neuroscience contribute to education?
- [RQ3] What is the relationship between cognitive neuroscience and learning?
- [RQ4] What is the relationship between educational neuroscience and mathematics?

This documentation consists of scientific research published in scientific journals. These academic databases were utilized to locate and analyze pertinent articles: ScienceDirect, Wiley Sage Pub, WoS, and SCOPUS. Keywords such as "educational neuroscience", "neuropsychology in education", "math learning", and "neuroeducation" were utilized to search the pertinent reference materials.

In addition, for the collection of data, an analysis and application of the articles cited by the authors were conducted. Rather than merely mentioning the findings of other authors, it is essential that the study adopt a global perspective. For a subject as important as educational neuroscience, there should be the most comprehensive approach possible to the cognitive topic at hand. In the present study, research-related articles were used; however, no bibliographic review, regardless of how comprehensive it may be, can fully satisfy the scope of a scientific object because there is always the risk of omitting research, particularly those with limited disclosure.

4. Results

Educational Neuroscience brings many motivations, methodologies, and implications to education (Hardiman et al., 2012). There are cognitive neuroscientists who focus on educational problems related to the teaching task and the learning process through research and study. Educational neurology is applied cognitive neuroscience. There are also educational researchers and professionals who are interested in the consolidation and comprehension of the mechanisms upon which the neurosciences' findings can be applied to the improvement and development of education. Clearly, educational neuroscience can be understood as a part of neuroeducation, and the ever-expanding initiatives associated with the relationships between mind, brain, and education insofar as their expertise in proper application allows. Educational neurology offers significant opportunities for simultaneously and collaboratively addressing fundamental issues in both disciplines. At this intersection, it must be emphasized that the use of neuroimaging techniques, such as the electroencephalogram (EEG), positron emission tomography (PET), and functional magnetic resonance imaging (fMRI), constitutes the methods and approaches of neuroscience, through which the neural mechanisms of human development and learning are better understood, a prerequisite for the application of educational neuroscience (Ferguson, Anderson & Spreng, 2017).

The objective of the field of educational neuroscience is to identify and develop techniques for enhancing the learning experience. Online learning is a typical educational context that educational neuroscience can offer. Online learning is an educational process in which technology serves as a mediator, with the ultimate goal of facilitating two-way communication between instructors and students (Halkiopoulos et al., 2022). At this point, the ultimate motivation of educational neuroscience, which is learners' learning, is fully understood. The distinctive characteristics of online learning have been instrumental in the development of educational programs that aid in teacher preparation and enhance children's learning (Goswami, 2006).

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Therefore, it is evident that the motivations of educational neuroscience are centered on the enhancement of the ability and attention of learners, with the ultimate aim of enabling students to master the expected learning outcomes as determined by particular teaching and learning contexts (Halkiopoulos et al., 2021). Moreover, the interest lies in the learners' participation in the creation of new knowledge and in the storage of that knowledge so that it will be accessible and valuable due to its persistence. Regarding the aforementioned online learning, teachers must possess the methodology upon which the previously stated objectives will be implemented.

Based on recent research by Moser, Schroder, Heeter, Moran, and Lee (2011), there is a correlation between educational interventions and brain changes associated with learning. In addition, recent neuroscientific research demonstrates a correlation between learning and more traditional socioeconomic factors. Another defining characteristic of Cognitive Neuroscience as a learning science is that research institutions are beginning to support studies that concentrate on brain and learning process cross-sectional studies (Rato & Castro- Caldas, 2011). These instances involve well-known research programs, such as the Science and Engineering Education Research and Evaluation Program.

In conclusion, in order to fully comprehend the relationship between cognitive neuroscience and the learning process, it must be emphasized that brain imaging enables a comprehensive understanding of Memory's mechanisms, a factor that can assist the educational community in modifying or adapting their teaching so that students remember it better. Therefore, cognitive neuroscience depends on the development of techniques for examining the activity of individual cell populations in the brain (Newton & Miah, 2017). Additionally, complex cognitive functions such as attention and decision-making are related to the type of discharge of individual cell populations in particular brain regions. This fact distinguishes the manner in which behavior is studied, and the focus is on how the individual ultimately processes information (Thomas, Ansari & Knowland, 2019).

Additionally, it is important to note that research on the induction of cortical damage contributed to a deeper understanding of cognitive function. The case of patients with lesions in particular cortical regions who exhibit particular cognitive deficits. Additionally, as emphasized, imaging techniques (PET, MRI, etc.) provide the appropriate framework for comprehending the correlation between changes in the function of neuronal populations and particular mental activities in the living brain (Geake, 2005). Informatics has improved the standardization of neuronal population functioning, resulting in the development of models (Rees, Booth & Jones, 2016). At this point, it is important to mention the following functions associated with school learning:

- Working Memory (lateral frontal cortex)
- Short-Term Memory (hippocampus and other cortical areas)
- Decision Making (orbitofrontal cortex)
- Emotional mediation (limbic system and connected frontal areas)
- Symbolic representation-representation sequence (fusiform gyrus and temporal lobes)
- Conceptual connections (parietal lobe)
- Conceptual and motor rehearsal (cerebellum)

Neural contributions to the field of intelligence are regarded as indispensable for all school subjects, including mathematics, which will be discussed next, and thus for all forms of knowledge (Nottingham, 2017).

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The research of Grabner, Obersteiner, Smedt, and Vogel (2016) emphasizes that in recent years there has been a great deal of interest in the study and research of the neurosciences pertaining to the learning process of the cognitive subject of mathematics, and that the field of learning mathematics has emerged as an ideal place where neuroscience can be applied to education. Some research, exemplified by Anderson, Love, and Tsai (2014), examine the brain when a person does numerical calculations or attempts to answer numerical problems using algebraic calculations.

In addition, there are cases of research in neuroscience, such as Andrá, Lindstrom, Arzarello, Holmqvist, Robutti, and Saben (2013), that focus on brain processing associated with complex mathematical concepts, despite the fact that these are hardly associated with theories regarding mathematics education. These investigations reveal that mathematical activities stimulate particular regions of the brain and that the brain processes mathematical elements without providing any information about their instruction. It should be underlined that the exploration of the neuroanatomical substrate of particular mathematical processes is equally as important as the examination of how these processes can be mastered (Kurtulus, 2013).

Grabner, O., Smedt, & Vogel (2016) note that research based on neuroimaging techniques enables scientists to gather high-quality data regarding the temporal and spatial brain function associated to mathematical knowledge in individuals with varying degrees of competence. The frontal cortex, which is responsible for directing thought and strategy, is stimulated for sophisticated arithmetic calculations, but not for mechanical memory (Hwang & Hu, 2013). The parietal cortex, which is connected with touch, pressure, pain, and temperature perceptions, is afterwards responsible for determining numerical ability and processing numbers (Day & Sweatt, 2011). Three distinct regions of the parietal cortex are connected with numerical processing (Sabitzer, 2011). The horizontal intraparietal lobule is important for computation, while the posterior superior parietal cortex is responsible for number processing.

In contrast, it has been discovered that the angular gyrus (AG) is involved for the verbal processing and retrieval of numbers (Ansari & Lyons, 2016). The inferior parietal cortex is related with symbolic numerical abilities and is responsible for the sensations of sight, hearing, and touch. In the normal situation of pre-learning, the mechanical numerical abilities are found in the subcortical basal ganglia and the cortico-subcortical circuits.

In relation to fundamental quantitative skills, algebraic talents also have a particular role. Furthermore, the parietal cortex has been linked to algebraic equations and the creation of geometric proofs. Lastly, it should be mentioned that there is emerging data based on the research of the brain that identifies dysarthria, dementia, and cognitive loss in numeracy and mathematical aptitude (Chang, Wu, Lai, & Sung, 2014). Consequently, the aforementioned findings illustrate that mathematical operations engage specific brain regions and how the brain interprets mathematical data (Fischer, 2009).

5. Conclusion

By assessing and analyzing the aforementioned research information, it becomes evident that the neuroscientific community must comprehend the significance of its contribution to a better understanding of learning, a fundamental human activity. The methodologies of neuroscience give a framework for gaining access to the neuronal pathways that the brain follows and permit a deeper comprehension of its function. Since the brain is the main mechanism of learning, this motivates the education community. With the use of neuroscience's analytical tools, the innovative, inter-disciplinary area seeks to study and resolve issues associated with education and the learning process. Educational

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neuroscience can add significantly to the mathematics curriculum. Neuroeducation can demonstrate the required ways for teaching, adapting, and utilizing cognitive functions. Educators highlight neuroscience in order to comprehend the structure and function of the brain and the learning-influenced cognitive development of humans. Consequently, the involvement of young researchers in Neuroscience constitutes valuable research that will not only benefit education but also society as a whole. Conclusions drawn from this study pertain to the implementation of novel and more effective instructional approaches to encourage and strengthen individualized learning in every way. In conclusion, neuroscience is an interdisciplinary cognitive field that investigates the strategies and methodological tools used to explore, research, and understand the nervous system's complicated mechanism.

Through educational neuroscience, the mechanisms of learning are studied and understood based on brain functions, the causes and reasons for the development of developmental disorders are investigated, the theories related to developmental disorders are examined and studied, the early detection of students with a high probability of developing developmental disorders is studied, and, as a result, early intervention is conducted in regards to the research of developmental disorders. In this light, the neurosciences provide a fundamental approach to a broad interdisciplinary subject that integrates the natural sciences and the humanities or social sciences, providing research data for the discovery of contemporary mankind.

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