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Implications of neuroscience/neuroeducation in the field of education to enhance the learning outcomes of the students

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Abstract

Neuroeducation or educational neuroscience, an emerging and interdisciplinary field is progressing to make a significant impact in the students' learning outcome by translating neuroscience data of the brain's learning power to pedagogical practices. In this review article, the implications of educational neuroscience in enhancing the students' learning outcomes are addressed. Learning outcomes in students can be affected by multiple factors that include child factors (e.g., cognitive ability) and school factors (e.g., curriculum). Neuroscience research data emphasized on the difference in the cognitive and emotional capabilities of individuals and mapped them to a certain part of the brain, thereby indicating a difference in their learning abilities. This neurobiological basis of learning has laid the foundation of neuroeducation and has led to a paradigm shift in traditional education by emphasizing on neuroscience-based educational curriculums and educational policies. The neuroeducation approach has improved the students' learning outcome in areas like mathematics, reading, etc.; however, this could be limited by the teachers' understanding and approach towards neuroeducation. Therefore, more research is required to substantiate the implications of neuroeducation in the students' learning outcomes. Since the field of neuroeducation is still in the nascent stage and translating lab data to the teaching-learning process is under progress, certain recommendations are made to implement neuroeducation in learning and meet the associated challenges.

Keywords: Cognitive, Education, Learning outcome, Memory, Neuroscience, Neuroeducation, Teaching.

1. Introduction

Neuroeducation, a new and dynamic field, links the two terms neuroscience and education, wherein neuroscience is related to the brain or the mental process and education is related to the teaching and learning processes.1 In 2010, Carew and Magsamen2 defined neuroeducation as a nascent discipline, which blends the field of neuroscience, psychology, cognitive science, and education. According to Howard-Jones,1 neuroeducation is an interdisciplinary field that links multiple disciplines like neuroscience, biology, cognition, psychology, and education. These assertions give a biological perspective to learning and prompt policy makers to integrate the perspective for designing effective teaching methods, educational policies, and school curriculum. The term 'neuroeducation' is often interchanged with brain-based learning, educational neuroscience, or 'mind, brain and education'.3

Neuroscience can be linked to education directly as well as indirectly. In an indirect pathway, neuroscience is connected to

education via psychological factors, such as working memory, attention, etc., whereas in a direct path, non-psychological factors like energy supply, diet and nutrition, air pollution, etc., influence the brain's functioning including learning.4 Interlinking the two terms, the basic foundation of neuroeducation is based on the brain's capability of performing multiple functions, such as memory, emotions, problem solving, etc., which are actively used while learning. To put it simply, the brain internalizes the meaningful learning through its functions. The research put forth by neuroscientists is mainly aimed to understand the mechanism of learning and the varying learning ability of individuals.5 Currently, this new discipline is being used not only to understand an individual's capability to learn and create methods to devise new learning strategies, but also as a tool to frame a science-based education policy for facilitating the learning.5 This review is not a comprehensive review on neuroeducation and the biological process involved in the assimilation of information by brain. Rather, the primary objective of this review is to consolidate the literature, which addresses the implications of neuroeducation in enhancing the students' learning outcomes and examines the role played by teachers in enhancing the students' learning outcome.

1.1 Brain function in neuroeducation

Right from early childhood, the human brain is constantly developing and it is capable of developing competency and at the same time becoming vulnerable. In the context of learning, both emotional and mental stimuli are essential for the brain to process the learning and they are unique for individuals.

Brain coordinates multiple functions like memory, cognition, decision making, goal setting, problem solving, following rules, gratification, etc. However, the major functions that interest neuroscientists in the learning process are working memory, cognitive flexibility, and inhibitory control. These three functions are regarded as 'the air traffic control system' of the brain.6,7 Working memory involves the storing of information and using it as required, e.g., following directions. Cognitive flexibility involves multitasking, switching from one task to another, adjusting with ideas or rules as per the need, and being attentive at all times. Inhibitory control involves the consideration of the possible outcomes of an activity, control of one's impulses, and planning.

Neuroeducation is also applicable to other psychological factors like attention, cognition, emotions, memory, executive control, motivation, social behavior, neurodiversity, and so on. These factors are important because the brain matures at different rates in every individual and this difference is reflected in the readiness to learn.6

Globally, education is based on traditional principles that involve the practice of sitting, watching, listening, and writing. In this mentalistic educational approach, the body and mind are not linked and individual differences are not accommodated.8 As a result, there has been a poor academic performance, low innovation, poor creative thinking, increased rate of failure, and school dropouts. All of these are negative outcomes of the traditional education system. Therefore, the academic interest for neuroeducation has tremendously increased to bridge the gap in brain-based learning and to apply knowledge in educational settings for facilitating the cognitive process of reasoning and learning in children.2

The application of neuroscience data in education is primarily guided by the scientific research outcome that specific neurotransmitters and brain circuits are associated with definite types of information.9 Some scientists have related neuroscience to the activation of amygdala or hippocampus, which is associated with learning and memory.10 Neuroimaging data has also indicated complex interaction in areas of the brain, thereby suggesting the possibility of more than one strategy in learning for diverse and struggling learners.11 Therefore, it can be inferred that neuroeducation considers an individual's cognitive and emotional factors in learning and it emphasizes the process of teaching and learning at the cerebral level.12 There could be some more scientific reasons to associate the brain with the learning capability.13 However, teachers are more interested to know how neuroeducation can be used to improve the teaching-learning process and how learning outcomes in students can be enhanced. Therefore, the interest of this review is also limited to the same.

2. Neuroeducation and learning outcome

According to researchers, the human brain has the natural ability to learn and the process continues beyond classroom learning. As an individual grows, the learning of new information and the evolution of thinking continues by the virtue of the activation of three distinct parts of the brain, namely, motor, memory, and thinking and reasoning areas. Parallelly, there has been a change in the brain's activity, indicating a bi-directional collaboration between neuroscience and education.14 In education, much emphasis has been given on learning outcomes, which include knowledge, understanding, and performance attained after the process of learning.15 The learning outcomes in any education system are influenced by multiple factors, such as child factors, school factors, societal factors, familial factors, and governmental factors. The main goal of neuroeducation is to improve educational outcomes by influencing all layers, but largely by changing the proximal factors. Such proximal factors are the child factors that include attention, motivation, nutrition, health, and ability, followed by the school factors that include teaching material, teachers' skills, classroom environment, and school policies.4

The field of neuroeducation has gained momentum after the 2009 Neuro-Educational Summit.16 According to neuroscience, spacing effect, i.e., the delivery of information in small bits or chunks, aid in memorizing and assimilating diverse information. Further, the use of visual platforms and interactive assessments help in the higher order of thinking.9 Therefore, researchers are trying to use neuroeducation as an intervention to deliver maximum benefits of training. Neuroeducation has been effective with respect to multiple learning outcomes. Presently, neuroeducation has made a significant advance in the domain of reading, followed by numeracy, and arithmetic.17 Grant18 used a neuroeducational approach to connect co-morbidities like dyslexia (reading disability) and dyscalculia (mathematical disability) with brain impairment. Impairment of multiple functions, such as domain-general deficits and domain-specific deficits, are mapped to the difference of brain development, especially the left angular gyrus. Domain-general deficits include verbal working memory and verbal semantic memory, and domain-specific deficits include phonological and numerical deficits. Neuroscience research indicates that the learning process depends on the neuronal activation and connections, and that classroom teaching and listening does not necessarily lead to learning. Research on neuroscience suggests that individuals may follow different learning pathways because of individual differences.19 Neuroscientists believe that teaching and learning are biological phenomena and therefore, a child and a teacher cannot be held solely responsible for an ineffective learning and teaching process.

A school is the learning center for children. Besides offering an emotional and affective environment, a school must render an effective learning strategy that involves a neurocognitive dimension. This would be a great platform for the students' learning and professional development.20 In the past few years, many educational programs have tagged neuroeducation in their curriculum to attract parents and improve business. Neuroeducation has progressed over a decade and few studies have attempted to explore its implementation in the current education system and their implications in enhancing the students' learning outcomes.

Brain-based strategies were used to teach science to seventh grade students and it was found that their self-esteem was enhanced and their performance was improved.21 Further, the projection of short audio-visual content in classrooms generated higher attention and emotion among university students, indicating that expressive resource materials with audio-visual content increases alertness.22 Similarly, a positive impact of neuroeducation was observed in adult learners' identity.

Visual-based learning strategies were effective in the social and cognitive growth of K-12 learners.23 Schnitzer24 found that despite teachers' lack of awareness about neuroeducation, fifth grade students showed improved performance. The use of neuroscientific findings, such as the brain's reward system in game-based teaching app called zondle Team Play (zTP), indicated the practicality and effectiveness of the teaching method. Students demonstrated excitement,

emotional involvement, and effective communication with their teachers.25

During the COVID-19 scenario, Espino-Díaz et al.26 reasoned the benefits of combining Information and Communication Technology (ICT) and neuroeducation in the teaching-learning process. In the current situation, where educational centers are closed, there is an observable shift from face-to-face education to online education, where both teachers and students are confined in their homes. Additionally, an increase has been witnessed in social stress, health stress, depression, and other consequences caused by the exceptional circumstances.

In this context, the author believes that the neuroeducation approach could be helpful in managing emotions and in motivating students.

2.1 Learning outcome in different areas

The neuroeducation approach has found relevance in multiple areas, such as reading ability, language, scientific and mathematical capabilities, developmental disorders, etc.

2.2 Reading ability

In a study, the US schools introduced programs like BrainGym that involved short psychomotor activities to encourage learning and to improve the reading abilities of fourth graders.9 This study associated physical activity with increased electrical activity of the hippocampus, which in turn resulted in improved learning and long-term memory. In a case study, a Brain-Targeted Teaching (BTT) model was implemented in an early childhood learning center (Intellitots) in Gurgaon, India. Its focus was on improving the emotional state and the physical environment and creating a productive learning experience. Theme boards consisting of colorful images and icons were found to be effective in improving the learners' reading abilities.27 Teachers' experience and their BTT methods collectively contributed to an improved efficacy in adopting the BTT model for the early childhood program.

2.3 Language

A critical component of literacy is language acquisition and function, because language mediates thinking. Arwood's Neuroeducation theoretical framework was adopted in a language classroom with an overlap of cognitive psychology, neuroscience, and language theory. It resulted in improved language proficiency among 90% of the students over a period of nine years.28 Among the various approaches used in neuroeducation, the narrative inquiry study of Murphy29 revealed the use of visual methods and informal assessments in language-based neuroeducation program with merits that included the fulfillment of students' needs, positive outcomes, and a paradigm shift. Kindergarten students showed improvement in their language function after the implementation of Arwood's Neuroeducation model and the delivery of neuroeducation-based writing instructions. An 8-week intervention program resulted in the improvement of language function characteristics in both oral and written language skills.30

2.4 Science and Mathematics

Implementation of the neuroeducation method resulted in the improvement of concentration, memory, reading abilities, and mathematical abilities of school children, who were from low-income households and who faced social issues like violence and drug addiction.9 Although there is no real scientific evidence on how neuroeducation works, scientists feel that neuroeducation can address issues related to deficits in reading and mathematical capabilities of young children.9 The neuroimaging data has associated mathematical proficiency in children and in adults to different parts of the brain.31 When compared to Project-based Learning, the utilization of Brain-based Learning was found to be more effective in the students' learning outcome of Mathematics.32 It can be inferred that neuroscience can be implicated in designing curriculums to suit learners based on their age groups and cognitive capabilities.

Students were subjected to a MRI scan, before and after the completion of Modeling Instruction (MI) in introductory physics, under a neuroeducation experiment. It was revealed that the brain activity was enhanced in the lateral prefrontal and parietal cortices, and the performance of students was improved in a physical reasoning activity. The parts of the brain, which are together referred to as the central executive network, are associated with working memory, attention, and problem solving abilities.33

Zhang34 used neuroeducation to design the content and the teaching strategy for an advanced course in computer programming. The connection model increased the learning process and the teaching strategy by breaking the 'straight line model' of classroom teaching, by shuffling the order of chapters, and by establishing 'skips' between the current and the past information. The researcher could recollect the past cognition through the model, which resulted in a faster acceptance of knowledge. There was an improved computational thinking ability when the students' cognitive psychology and physiology were used to reform the programming course. Similarly, a seven-week neuroeducation intervention resulted in an increase in perseverance among students pursuing educational doctorate or specialist degrees. This intervention was effective in reducing the attrition rates of students who were pursuing online doctorate degrees.35

2.5 Learning outcome in students with special needs

Neuroeducation intervention is also explored among children with speech or language disabilities. A combination of neuroeducation intervention and Neurosemantic Language Learning Theory (NLLT) improved the intelligibility and language function of children with suspected Childhood Apraxia of Speech (sCAS).36 Students identified with emotional and behavioral disorders (EBD) and language impairment were able to acquire pro social behavior through the neuroeducational approach. The studies reflected on the interaction of cognitive psychology, neuroscience, and language in neuroeducation, and supported the Neuroeducation theoretical framework of Arwood.37

A handful of research studies outlined in this review clearly indicate a positive influence of neuroeducation in enhancing the students' learning outcomes. Research related to understanding the brain's function in learning is emerging in neuroscience. Few studies18,33 have associated certain brain regions with cognitive abilities, indicating that modified curriculums and teaching practices can enhance the brain's activity and improve the learning outcomes. Therefore, it is essential to shift from traditional teaching practices to the emerging knowledge of neuroscience, update the curriculum and the teaching strategies, and enable students to attain an effective learning experience.

In order to summarize, neuroeducation is required to facilitate the fundamental learning, considering the cognitive and emotional peculiarities or any mental disorders of an individual. In this regard, the approach of educators in extrapolating neuroscience to classroom teaching is vital.

2.6 Role of teachers in students learning outcome

Neuroeducation is a novel field and it has benefitted students. However, the implication of neuroeducation in students' learning outcomes depends on the educators' approach, suggesting a critical role of teachers. The qualitative study of Shepherd38 included a multitude of typological variables, such as prior knowledge, reinforcement, emotion, etc. The study revealed that middle school teachers lacked awareness and knowledge of neuroeducation pedagogy and the link between the brain and the mind. This could likely result in a lack of applying neuroeducation in the learning-teaching process. Likewise, Murphy29 found that self-efficacy, lack of willingness, and mindset mismatch can be the barriers in the implementation of neuroeducation. Lack of awareness in neuroeducation pedagogy was also found among educators of adult learning.39

On the contrary, the mixed method in a study of US teachers revealed that an understanding of the brain's function is essential for the screening of learning problems and for decoding the provision for individuals with special education needs, such as cognitive, physical, behavioral, or emotional. It was also found that neuroeducation could help in the designing and delivery of educational programs.40 The authors found that teachers from the US showed enthusiasm towards neuroeducation; however, they did emphasize that communication is not required between neuroscientists and educators, indicating their reliance on secondary sources (e.g., books or conference journals) for information on neuroeducation. The teachers highlighted the importance of the availability of neuroeducational material and its relevance in classroom teaching.40

Hook and Farah16 interviewed teachers who attended 'Learning and the Brain' conferences and found three main points for educators, namely, educators' motivations, impact on classroom practice, and practical benefits. Educators' motivations were caused by their curiosity to know about the novel teaching strategy, intellectual stimulation, and knowledge enrichment on multiple aspects. These aspects include the brain's teaching function, bridging of the gap between neuroscience and education, and adopting a holistic approach on teaching, where the brain is involved. The most important aspect is the practical application of neuroeducation in the teaching process and in other disciplines. The impact on classroom practice varied, but it mainly showed improvement in the level of interaction with children, teacher's investment of their time and efforts, and their planning of classes. Other practical benefits included affirmation and authority, maintaining perspective with difficult students, professional satisfaction, and enhanced self-image. Teachers supported several strategies, such as modification of physical classroom environment, change in lesson structure, use of graphic organizer, etc., and demonstrated an effective neuroeducational approach.16

Studies show that neuroeducational training is essential for teachers. In this context, Compagno and Pedone41 used neuroeducation micro-planning activity for training the teachers. This activity was based on the Theory of Multiple Intelligences. The trained teachers could use cognitive and intellective factors to develop a structured, neuro-oriented, and methodical teaching strategy in a competent manner. The teachers were able to develop a meaningful communication and interaction with their students.

Since there is a lack of empirical studies related to the integration of neuroscience with education, Luzzato and Rusu42 created a questionnaire in their pilot study to address the self-efficacy and attitude of Israeli teachers who implement neuroeducation and train students. Their study revealed that psychosocial characteristics, such as self-efficacy and attitude, could bring a positive change. Israeli pre-service teachers (PSTs) showed a positive attitude and willingness to invest their time to introduce neuroeducation in teaching and learning; however, their low self-efficacy reflected their lesser knowledge of neuroeducation.42 It can be summarized from the reviewed articles that teachers' knowledge on the development of brain and the training programs in neuroeducation could improve their interactions with students.41

3. Challenges in neuroeducation

The main goal of educational neuroscience or neuroeducation is to enhance the brain's ability to learn through the transformation of the learning environment.43 In this context, the information generated by synergistic interactions among multiple disciplines, such as cognitive psychology, neuroscience, and education, is used to develop effective teaching and intervention strategies, curriculum, and educational policies.3

However, the credibility of neuroscience in education is not firm yet. Despite the positive perceptions of scientists and parents on the advantages of brain-based teaching in education, a relatively low implementation of neuroscience in educational processes was found in the reviewed literature, indicating the challenges at multiple levels. One of the key issues among educators is the low knowledge and awareness on neuroscientific research.3 Educators are more interested in the applicability and effectiveness of neuroeducation in teaching. Another issue is the common belief held by the non-scientific population that neuroeducation is being promoted to disengage the common neuromyths or false claims like a smaller percentage of brain usage, gender-bias, etc.

As pointed out by Thomas et al.,4 the science behind learning by brain is a very complex and interactive process. However, the society is targeted more towards classroom learning, when referred to education with low clarity. Further, it could be challenging for researchers and educators to translate the process of brain-based learning to educational practice, curriculum design, and teaching strategy. Additionally, academicians and researchers have been warranting the credibility and effectiveness of a curriculum wrapped with neuroeducation.

More evidence is necessitated to prove the effectiveness and validity of brain research and its implementation in classroom teaching is an altogether different subject. Finally, in the words of neurologist Judy Willis, scientific results on neuroeducation can only be correlated to their effectiveness in classrooms.44

4. Recommendation

In order to integrate neuroeducation in classroom teaching, educational policies and educational practices have to be revamped. Rather than considering standardized testing and curriculums, emphasis should be given to the cognitive capabilities of an individual. Information on scientific research on neuroimaging and other aspects of neuroscience is important; however, the extrapolation of these aspects into the real world would be more productive. In this regard, the applicability, limitations, and practical approach of neuroscience in the field of education should be put forward. Few points are revised in this review, based on the recommendations by researchers.4,5,45

Educational policy makers must be open to new research, be aware of the differences in the cognitive and emotional abilities of children, and thoroughly study before reconfiguring the policies and practices. Considering the psychological factors, the education strategies must be derived and implemented to enhance the students' learning outcomes. Universities must have experienced teachers and faculties trained in the fields of neuroscience and psychology. Teacher preparation programs involving faculty training and professional development in education-related neuroscience and cognitive science46 must be extended to teachers of all backgrounds including those associated with Special Educational Needs. Simultaneously, neuroeducational engineers should be hired. Altogether, this will prompt teachers to adopt alternative teaching strategies. Students should also be persuaded to obtain training in neuroscience.

Any teaching strategy must be supported by a legitimate research. On this subject, educational resources and print-media should not add brain-based jargon to improve their sales. Further, a 'bench to bedside' approach is required in the field of neuroeducation. Scientific researchers must try to connect the findings of neuroimaging data with classroom practices.12 Collaboration and exchange of knowledge between neuroscientists and educators will help to identify the real issues faced by teachers and aid researchers to address the same in their lab research. Since the penetration of ICT has tremendously increased, neuroeducation can be merged in the education sector. Adaptive learning technology involving personalized learning should be emphasized to benefit individuals with or without disabilities.

Neuroscientists have been baffled by the human brain for centuries. Although neuroscience has made significant progress in certain areas of brain functions, such as association of neural areas with cognition, emotion, and motivation, there is still more to discover. The link between neuroscience and education has been made long time back, but it has gained momentum only over a decade ago. Its implication in education is not confirmed due to the difficulty in translating neuroscience data to the learning process. However, there is some ongoing research on positive learning outcomes among students regarding the use of neuroeducational approach in classroom teaching. Thus, educators and policymakers must understand the potential and limitations of neuroscience data, and develop new pathways to facilitate learning among students.

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