MATHEMATICS EDUCATION AND COGNITIVE NEUROSCIENCE: INTERFACES REVEALED BY RESEARCHERS FROM THE CANADIAN LABORATORY ENGRAMMETRON (EDUCATIONAL NEUROSCIENCE AND MIXED RESEARCH LABORATORY)

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ABSTRACT

This study aims to highlight the interfaces between Mathematics Education and Cognitive Neuroscience revealed by the Canadian research group of the ENGRAMMETRON laboratory (*Educational Neuroscience and mixed research laboratory*) of *Simon Fraser University* from some aspects and results achieved by the group. According to the Canadian group, Cognitive Neuroscience seeks to highlight the role of the neurophysiological mechanisms underlying cognitive functions and to identify the mind-brain mechanisms that enable us to develop new teaching and learning strategies. In this way, I seek to highlight the main ideas pointed out by the group in the context of Mathematics Education and Cognitive Neuroscience. I emphasize that the focus will be given, primarily, to the perspective of the mathematical educator and, in a second focus, to that of the neuroscientist, valuing the interdisciplinary and multidisciplinary context of teaching and learning.

Keywords: Mathematics Education. Educational Neuroscience. Cognitive Neuroscience. Mind-Brain-Behavior Relationship. ENGRAMMETRON.

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INTRODUCTION

The purpose of this study is to highlight the main aspects and results evidenced by the working group of the ENGRAMMETRON laboratory of *Simon Fraser University* coordinated by the researcher Stephen R. Campbell regarding Educational Neuroscience and, more specifically, the phenomena pertinent to Mathematics Education aligned with the perspective of Cognitive Neuroscience. The choice of this theme is justified by the proposal to deepen and extend the studies that interface Cognitive Neuroscience and Mathematics Education, the cognitive and neurobiological aspects associated with the mathematical mind of the individual.

Thus, it is part of this work to enter the multiprocessable, active and participatory system that corresponds to the human brain, in order to highlight some possible contributions of current research and relationships that are established in an interdisciplinary and multidisciplinary context between Neuroscience and Mathematics Education, in addition to pointing out what possible future perspectives are related to the theme. To this end, based on the ideas and results of research coordinated by Stephen R. Campbell, I highlight in this study the possible contributions of Cognitive Neuroscience in Mathematics Education from the perspective of the Canadian group.

Next, I present the researchers' perspective on Mathematics Education from the point of view of Cognitive Neuroscience, as well as a little of the history of the formation of the ENGRAMMETRON laboratory.

MATHEMATICS EDUCATION FROM THE POINT OF VIEW OF COGNITIVE NEUROSCIENCE AND SOME IDEAS PORTRAYED BY THE ENGRAMMETRON STUDY GROUP

According to the ideas portrayed in Campbell (2010), the phenomena pertinent to Mathematics Education have been studied from perspectives aligned with Cognitive Neuroscience, and have promoted a new era of investigation and new opportunities for educational research. In his work, the author states that the results published in his research are still suggestive, illustrative and still incipient and cannot be considered definitive or comprehensive. The term Neuroscientific Education or Educational Neuroscience becomes constant during the presentation of their work and reveals what Canadian researchers call the movement known as "brain-based education" (CAMPBELL, 2010, p. 310). As the author points out, a huge gap seems to arise between the study of physiological structures and their mechanisms related to learning, either due to lack of interest or misinformation in the areas of research that relate the processes of mathematical cognition and learning, such as cognitive psychology, cognitive neuroscience and neurogenetics (CAMPBELL, 2010). From this context, the author points to a question that seems to be inevitable in this scenario: why bother to fill this huge gap?

In his description, the study of mental functions, brain structures, and physiological behavior has advanced as a result of the dedication of cognitive psychologists, computer scientists, neuroscientists, as well as psychophysiologists and geneticists. Also, according to Campbell (2010), interdisciplinary studies related to Cognitive Neuroscience have been fed by a growing knowledge base of studies of brain injuries and their impairment of functioning, in addition to technological advances in brain imaging that expand vision and the study of their physiological and behavioral structure. Thus, the author describes that recent advances in the study of brain-imaging have led to a greater interest on the part of researchers in knowing the role of Neuroscience linked to Education and vice versa. In addition, the researcher describes that certain imaging techniques have opened new windows for the study of the structure and behavior of the brain, correlating its anatomy, behavior, and mental function based on the identification of brain oscillations in the human cortex as a result of mathematical thinking that can range from deep *insight* to profound aversion.

Therefore, as the Canadian researcher points out, initiatives have sought to establish the relationship between the research areas, involving parts of Cognitive Psychology and Cognitive Neuroscience, in addition to Mathematics Education. The author calls this union Mathematical Educational Neuroscience and identifies in it the potential to deepen the understanding of mathematical cognition and learning, in addition to becoming an important, if not, revolutionary area of research in Mathematics Education.

It is perceived that in all the work of the Canadian group, the relevance of Neuroscience in Psychology and Education is evident and the existence of different answers to the same questions, as a result of different levels of analysis carried out on them. This becomes notorious when the answers are given from the analysis given by physicists, physiologists or psychologists on themes common to their respective areas. However, it is noticeable that researchers in education are reluctant to reduce psychological issues to physiological views, much less to views related to Biology, Chemistry or Physics. It is important to report that there are interfaces between these different levels of analysis and, especially, between Psychology and Physiology that must be interrelated in a coherent way.

Campbell (2010) describes that emotions can be perceived from anxiety that is related to the organs of the body connected to the brain from the peripheral nervous system, such as the skin, heart and lungs. Thus, cognitive emotional responses correspond to alterations in the brain system associated with a variety of cognitive functions, such as perception, memory, creativity, reasoning, and others, making evident the embodied manifestations of human cognition from objectively observable aspects. Therefore, the fundamental assumption of Educational Neuroscience considered by Campbell (2010) is that human cognition is also incorporated into human physiological aspects.

Thus, the researcher describes that

> Every subjective sensation, memory, thought, and emotion—anything that any human being can ever experience—is, in principle, decreed in an objective manner, observable as an embodied behavior. Although all embodied behaviors are an "integral part" of the ongoing subjective flow of lived experience, in addition to the empirical study of evident behavior, a deeper view of cognition and learning ensures measurements, analyses, and interpretations of physiological changes (CAMPBELL, 2010, p. 313).

The same author emphasizes that Cognitive Neuroscience should not be solely scientifically oriented in terms of neural structures, their biological mechanisms, computational processes and their functions. On the other hand, Cognitive Neuroscience should emphasize a humanistic orientation oriented to Educational Neuroscience, as a new area that will access its methods, especially summoned for the purposes of the experiences lived by educational practices and problems.

Among the educational problems pointed out by the author are those related to the anxiety that certain students have in relation to their learning, highlighting the eminent need to study what types and to what extent positive and negative emotions promote or hinder various aspects of involvement, reasoning and performance in solving mathematical problems.

In Campbell and Patten (2011), the authors bring a compilation of the group's research that relates Educational Neuroscience to motivations, objectives, theories, methods, investigation techniques and future perspectives. The research of these same authors directs to a wide range of initiatives and questions and highlights the need to establish a common language among all areas of knowledge involved.

As the researchers explain, from a scientific point of view, greater observation of perspectives arising from the study of the brain, body and behavior can promote the creation of better opportunities in measuring, identifying and understanding new phenomena and significant factors associated with the cognitive and social development of various aspects of teaching and learning, in order to elevate and better identify our understanding of the human condition.

Also according to the research of the same authors, the fundamental assumption of Educational Neuroscience is that all human cognition, that is, all subjective sensation, memory, thought, and emotion can, in principle, be observed from the behavior of the human organism. However, they show that all physical behavior is only a part or part of the subjective flow of lived experiences that are observed, analyzed and interpreted based on physiological changes that can be visualized by appropriate methods and techniques. Consequently, physiological changes, seen and analyzed by brain imaging, can reveal fluctuations in brain state that are related to affective aspects and cognitive functions.

Campbell and Patten (2011) expound, in a positive way, that the focal point of Educational Neuroscience is in living human beings, and is not limited exclusively to the physiological and biological mechanisms underlying them and that, in general, they are evidenced in a materialistic perspective from causal effects that are manifested as objective changes in the body, brain and behavior.

The aforementioned authors add that the term mind-brain should always be considered in a single and integrated way and never separately and that the validity, reliability and relevance of theories of teaching and learning in Education research can be variably corroborated, refined, or refuted from neuroscientific studies and/or with the use of methods that test hypotheses of a particular theory.

Therefore, some specific questions observed by the same authors are appropriate: to what extent can anxiety related to mathematics prevent its understanding? And to what extent can we control such anxiety? Other more specific questions are: what types and to what extent do positive and negative emotions promote or prevent aspects of engagement, reasoning and performance in solving mathematical activities? In this way, relating emotions to physiological behavior allows the clarification, at least partial, of issues such as those previously pointed out.

Campbell and Patten (2011) state that the answers to the previous questions may take many years of study, perhaps decades, and argue that the objective of Neuroscientific Mathematics Education is to help in the investigation and establishment of these connections from the provision of evidence portrayed in methods such as, for example, pupil response, electroencephalogram, skin response and respiratory rates. In this way, aspects of perception, solution and understanding can be evidenced, allowing us to validate or refute hypotheses previously outlined can, in addition to providing a deep and better understanding of the aspects inherent to the teaching and learning of mathematics

Neuroscientific Mathematics Education corresponds, therefore, to a bridge that will make explicit the interdisciplinarity between the areas, identifying the neuro-mechanisms underlying cognitive and behavioral functions and that comes to test and refine the more traditional models, questions, problems and studies, cultivating mathematics as the center of the problem.

Such interdisciplinary aspects reflect the life experiences that are manifested in the brain, body, and behavior in some way, and bring methodological concerns shared among physicists, engineers, mathematicians, and educators.

The aforementioned comments regarding the incorporated manifestations of lived experiences have offered a spirit that provokes change and that educational research cannot renounce such humanistic orientations.

In view of this new inherent perspective of studies, the ENGRAMMETON laboratory was born in 2005/2006, coordinated by Professor Stephen R. Campbell. Calling himself a knowledge engineer, Campbell found technological systems that defined good rules and good objects, reflecting the classic physiological problem of reconciling perception and intellect and pointing to the importance of pattern generation and recognition. Among the questions highlighted by Campbell (2007) is: but how to develop a neural network capable of dealing with both perception and logical inference? Its objective is to understand how humans are able to do and learn tasks, and to establish the relationship between perception and intellect as a result of this challenge. Still, from this perspective, Campbell (2007) is faced with another important question: how do we learn to recognize and generate patterns, that is, mathematical patterns?

In Campbell (2007), the researcher describes that mathematical perception and cognition can be evidenced in experiments described by models of cognition and learning based on brain images and their behavior. With the proposal to deepen these studies, the group of researchers envisioned the creation of the ENGRAMMETON laboratory. Below, I discuss its history and operation.

THE EDUCATIONAL NEUROSCIENCE LABORATORY - ENGRAMMETRON

Created in 2005/2006 at the Faculty of Education of *Simon Fraser University* (Canada), ENGRAMMETRON corresponds to an Educational Neuroscience laboratory developed with the support of the Canadian Foundation for Innovation (CFI) and the Knowledge Development Fund of *British Columbia* and *Simon Fraser University* (SFU).

Today, ENGRAMMETRON is an educational research unit in the analysis of behavioral, psychometric and psychophysiological data, including studies that cover the analysis of audio, vision, eye movement, brain waves, heart rate, as well as skin conductance and temperature.

The initiative in the creation of this research laboratory had the purpose of justifying this new branch of study from the exploration of its theories, methods and practices. Campbell (2007) adds that the initiative in his creation refers to his interest in studying, while still an undergraduate, about the nature of consciousness related to educational practices and that, in the future, led him to become a neuroscientist. Thus, as the researcher reports, during his studies, he was enchanted by the physiological and mathematical aspects related to the mind that led him to deeply understand mathematical models and their applications. It is possible to affirm that such models and applications allowed him to relate and discuss how seismic images associated with other brain images can be associated with social constructions of new senses of perception. The same author mentions that the evolution of computational mathematics has enabled a new sense of perception and that it has been aligned with the development of artificial intelligence (AI) and the implications of using logic to model high-level cognitive functions.

Although it has in its name the theme Mathematics Education (ENGRAM/ME – *Educational Neuroscience Group for Research in Affect and Mentation in Mathematics Education),* the laboratory is not limited only to the study of mathematics, but to other educational areas such as Psychology, Kinesiology, Biomedical Engineering, Psychometrics, Psychophysiology, Sign Analysis, Neuropedagogy and Embodied Cognition of *Simon Fraser University* together in partnership with other universities, associations, professionals and industries from Canada and other countries. Among the areas worked, Campbell (2007) describes that psychometrics allows the level of anxiety that a student has in relation to mathematics to be investigated, which is often caused by the deficiency of inductive reasoning, slow decision-making, processing of superficial depth, reduced memory and performance, and limited attention. As he points out, psychometrics is considered an arm of psychology that deals with the design of instruments, administration of experiments, interpretation of quantitative data from the measurement, identification and classification of psychological aspects related to the abilities and personality traits of students, in order to provide guidance for the interpretation and analysis of psychophysiological data.

Thus, in this laboratory, possible correlations of cognition and learning between body and mind are identified, functioning as an incubator for the exchange of experiences, knowledge and information between researchers and various institutions.

Thus, it becomes possible to identify the activities performed by the group's researchers, which correspond to: (a) evaluating and improving the human-machine interface and the instructional design for learning; (b) investigate metacognitive factors associated with learning; (c) determine the role of sleep and fatigue in performance; (d) understand the extent and application of educational neuroscience methods and outcomes in classroom contexts.

FINAL CONSIDERATIONS

In this study, I sought to identify the main aspects and results evidenced by the working group led by Stephen R. Campbell regarding Educational Neuroscience and, more specifically, the phenomena pertinent to Mathematics Education aligned with the perspective of Cognitive Neuroscience. I emphasize that, as mathematics educators, we must emphasize the humanistic aspects aimed at understanding the real experience lived by the student, which are not limited only to neurophysiological processes. Thus, following the ideas of Campbell (2010), Educational Neuroscience prioritizes learning and seeks to identify the neural mechanisms underlying cognitive behavior. As pointed out by the Canadian group's research, there is a need for greater interaction between mathematical educators and neuroscientists, in an interdisciplinary language that relates various areas of knowledge, such as mathematical modeling, signal processing, psychological and sociological models, spectral analysis and brain structure. In this context, it is possible to say that Cognitive Neuroscience focuses on various aspects of brain behavior, aligning terms of neural structure, mechanisms, processes, and functions with humanistic aspects and the lived experiences of learners.

I show in this study that Mathematics Educational Neuroscience corresponds to a new area of research and, consequently, considers new opportunities in Mathematics Education.

I emphasize that I am still far from closing this discussion, but I leave here new possibilities and deepening studies that can guide and improve this line of research.

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