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Transdisciplinary epistemological foundations of education and neuroscience

Fundamentos epistemológicos transdisciplinares de educación y neurociencia

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Abstract

The emergence process of the new area of knowledge, product of the convergence between the fields of neuroscience and education, is still in its consolidation stage. At this point of disciplinary evolution, it is essential to define a multidimensional framework for creation of knowledge, in order to support the consilience between the academic fields involved. In this paper, a critical review of the literature associated with the epistemological questions is carried out, which underlies the attempt of communication between disciplines, providing a theoretical framework that starts from basic epistemic questions, to finally base the synergy between the sciences of education and the brain sciences. In the set of reviewed literature, the state of terminological undefinedness of the area referred to as "educational neuroscience", "neuroeducation", or "mind, brain and education" emerged explicitly. This inconsistency in the nomenclature is correlated in the epistemological ambiguity of the different proposals, as well as the need to overcome unidirectional models of communication. In conclusion, this type of relational model, located in the interdisciplinary framework, could be demanding an evolution towards a transdisciplinary approach: with the establishment of an effective bi-directionality that incorporates professionals and educational researchers as active agents in knowledge construction processes of this new field.

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Keywords

Education, neuroscience, psychology, epistemology, interdisciplinary approach.

Resumen

El proceso de emergencia de la nueva área de conocimiento, producto de la convergencia entre los campos de la neurociencia y la educación, se encuentra aún en su etapa de consolidación. En este punto de evolución disciplinar, resulta imprescindible definir un marco multidimensional para la construcción del conocimiento, con el fin de fundamentar la consiliencia entre los campos académicos implicados. En este trabajo se realiza una revisión crítica de la literatura asociada a las cuestiones epistemológicas, que subyacen en el intento de comunicación entre disciplinas, proporcionando un marco teórico que parte de cuestiones epistémicas básicas, para finalmente concretizarse en unas bases que fundamenten la sinergia entre las ciencias de la educación y las ciencias del cerebro. En el conjunto de literatura revisada emergió de forma explícita el estado de indefinición terminológica del área referida como neurociencia educativa, neuroeducación, o mente, cerebro y educación. Esta inconcreción en la nomenclatura encuentra su correlato en la ambigüedad epistemológica de las distintas propuestas, así como la necesidad de superación de modelos unidireccionales de comunicación. En conclusión, este tipo de modelo relacional, situado en el marco interdisciplinar, podría estar demandando una evolución hacia un enfoque transdisciplinar: con el establecimiento de una bidireccionalidad efectiva que incorpore a los profesionales e investigadores educativos como agentes activos en los procesos de construcción de conocimiento de este nuevo campo.

Palabras clave

Educación, neurociencia, psicología, epistemología, enfoque interdisciplinario.

Introduction

> We are not students of a specific subject, but students of problems. And problems can cross the boundaries of any subject or discipline (Popper, 1963, p.88).

Bolaños (2015) highlights the validity and permanence of the epistemological and methodological contrast between those fields of knowledge dedicated to the study of physical phenomena and those oriented towards the most abstract aspects of reality. However, Palgath, Horvarth and Lodge (2017) argue that when we consider issues that affect humanity, such as those that concern education, the complex and systemic nature of these issues requires the integration of ideas and methods from different disciplines, for the development of comprehensive solutions. According to De Corte (2018) the great complexity that underlies educational systems and pedagogical practice, profiles education as a crossroads where both dialogue and conflict can arise between a wide variety of disciplines. Historically, the dialogue of educational science or pedagogy with other sciences gave rise to the multidisciplinary product known as education sciences. This was the origin of the emergence of subdisciplines such as

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educational philosophy, the sociology of education, the anthropology of education, or educational psychology; all of them framed in the constructs of the social or humanistic sciences.

According to Flobakk (2017), the proposal of the incorporation of the biological perspective, and of neuroscience as one of its branches (and specifically in its aspect merged with cognitive psychology, cognitive neuroscience), waited until the end of the century XX to be formulated. Among the arguments raised by this attempt of disciplinary convergence arose the debate around the questions of how the philosophy of the natural sciences (neuroscience) and that of the social sciences (education) could come to concur. That is, how disparate approaches within the philosophy of science, manifested through different types of theories and methodologies could establish contact through the boundary lines in which education and neuroscience are framed.

In this attempt to bring the disciplinary boundaries closer, as indicated by Pohl and Hadorn (2008), it is necessary to discern about the methodological challenges, the complexity of the investigated problems and the diversity of epistemic perspectives. For this reason, this research work made a critical review of the literature associated with the challenges posed by the establishment of epistemic bridges between neuroscience and education. First, an analysis was made of the different relational dynamics in which the generation of disciplinary knowledge can be framed. Subsequently, those same dynamics were examined in the academic products which were grouped in different nomenclatures: educational neuroscience, neuroeducation, mind, brain and education.

Epistemological and methodological bridges between disciplines within the framework of the complexity sciences

Since the last decades of the twentieth century, the hegemonic legacy of the positivist science of the eighteenth and twentieth centuries has been questioned. This dialogue has highlighted the need to create, disseminate and manage knowledge through new more systemic epistemological and methodological approaches. According to Collado (2016b), Western schools of thought have allowed a great technological and material development for humanity, but the disciplinary hyper-specialization has put in check the conceptual and methodological frontiers of epistemological reductionism on which modern science relied. According to Santos

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(2010), this situation has allowed the emergence of new dialogues between the scientific disciplines themselves and other epistemes (art, spirituality, emotions, ancestral wisdom, etc.) in an ecology of knowledge. In a symbolic way, the passage from the nineteenth century to the twentieth century was called by the scientific community as the new Babel. The corpus of scientific knowledge acquired in that period gave rise to a 'knowledge inflation' and to the division of science into an infinity of hyperspecialized disciplines. This situation led Kuhn (1970) and Feyerabend (1997) to introduce the notion of incommensurability of knowledge in the history of science.

In this sense, the communication presented by Julie Klein during the First World Congress of Transdisciplinarity of 1994 is illustrative. Klein (1994) pointed out that of the 7 to 54 disciplines identified between 1939 and 1950, could be verified in 8530 areas of knowledge by 1987. As is logical, this inflation of knowledge originates new epistemological and methodological dialogues that made us rethink all scientific fields from new, more open approaches. According to Collado (2016b), cooperation between disciplines manifests itself as a new frontier of thought necessary to reform the problems derived from the reduction and fragmentation to which science, human reality and the ontological structure of nature were subjected. These disciplinary interrelations constitute an important epistemological and methodological dialogue to establish communication channels, in order to define an epistemic framework that bases consilience between different fields of knowledge. In the field of educational knowledge, the process of rethinking the sciences of education from different epistemic approaches involves articulating conceptions of human learning focused on overcoming unidirectional models of communication between disciplines. For this reason, Nicolescu (1996) synthesizes mono- (Figure 1), multi- (Figure 2), pluri- (Figure 3) and inter- (Figure 4) and transdisciplinary approaches (Figure 5):

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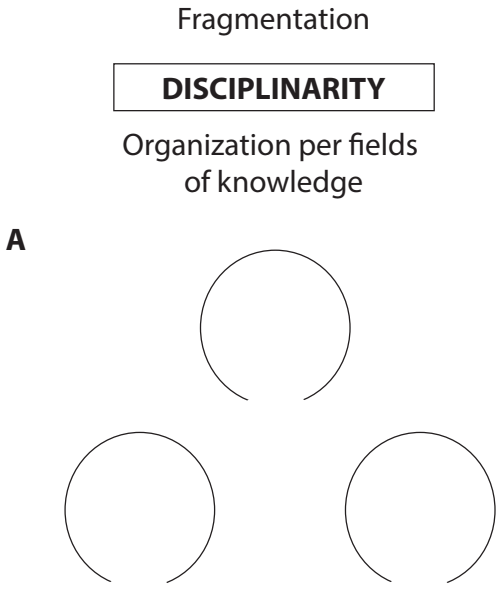
Figure 1
Disciplinarity



Source: the authors.

Disciplinarily: Represents the way of thinking and conceiving reality according to the demands of the modern scientific method, where knowledge is fragmented and converted into an object. Knowledge is organized in different disciplines or specific areas, where each of them has its own methodological rules. This epistemic-methodological process produces an increasingly atomized specialization of knowledge. In turn, the interrelations within a discipline, according to its internal logic, is defined as intradisciplinarity (pedagogy).

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Figure 2
Multidiscipinary

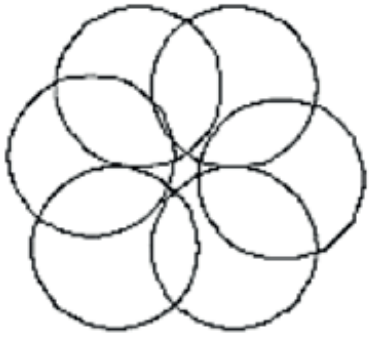
Generic

(Grouped Interdependence)

MULTIDISCIPLINARY

Coordination by standardization
investment in the entire system

B



Enter Information

- Each discipline is represented
- Multiple closed-systems interact in an open-system

Source: the authors.

Multidisciplinary: It deals with studying a research topic from several disciplines in a simultaneous way. From this perspective, any topic will be enriched with the incorporation of the points of view of various disciplines. Thus, the multidisciplinary approach exceeds the disciplinary limits, but its objective remains limited to the disciplinary research framework, since the disciplines cooperate in a mutual and cumulative way, but not interactively. The professionals involved in a multidisciplinary task adopt collaborative relationships with common objectives (e.g., education sciences).

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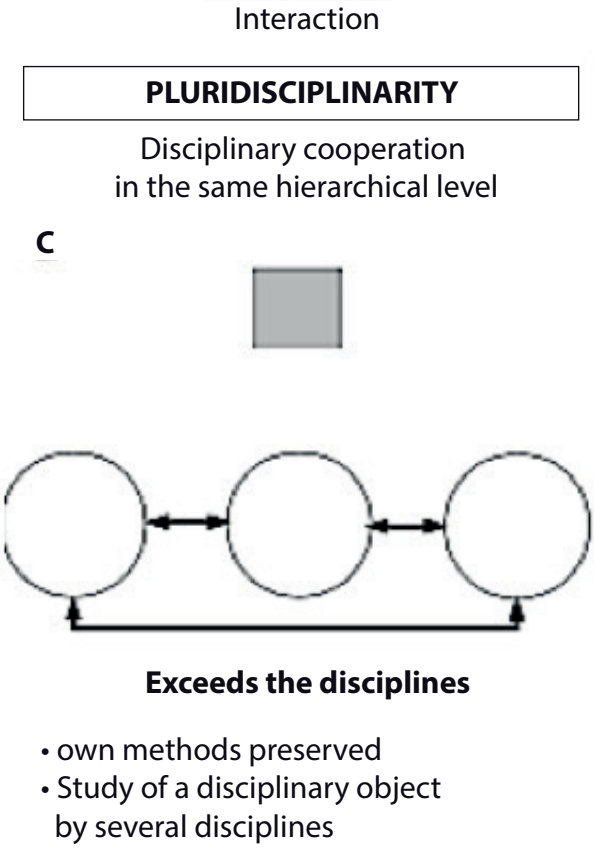
Figure 3
Pluridisciplinarity



Source: the authors.

Pluridisciplinarity: Study of an object of the same and unique discipline by several disciplines, located generally at the same hierarchical level, at the same time. The pluridisciplinarity approach goes beyond the disciplines through an interaction or disciplinary cooperation, where the own methods of each are conserved, and whose purpose continues inscribed in the disciplinary research structure.

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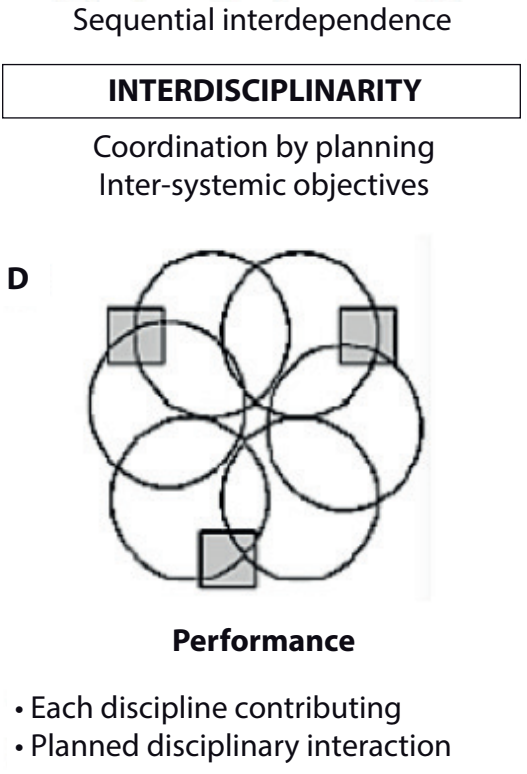
Figure 4
Interdisciplinarity



Source: the authors.

Interdisciplinarity: Prolonged and coordinated interaction between academic disciplines, leading to the integration of different discourses and the creation of a lexicon or common conceptual framework. Bridges are formed between the cracks of the disciplinary structures, arriving to formulate a common methodology that transcends the interface of the epistemologies of different disciplines. Interdisciplinarity is organized into two hierarchical levels, since a sense of purpose is introduced when the axiomatic common to a group of disciplines is defined at the hierarchical level immediately above. We can distinguish 3 types of degrees: a) application; b) epistemological; c) generation of new disciplines (e.g., educational psychology).

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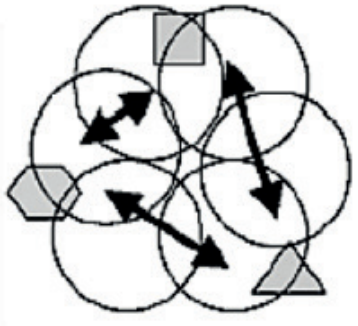
Figure 5
Transdisciplinarity

Reciprocal interdependence

TRANSDISCIPLINARY

Coordination based on individual and systemic dialogue investment in uncertainty due to the combined and sequential

E



Homeostasis

- Each discipline affects
- Reorientation

Source: the authors.

Transdisciplinary: Development of a general axiomatic crossing the essence of the disciplines. Prolonged and coordinated interaction between academic disciplines and knowledge produced by the subjects outside the academy (art, spirituality, ancestral knowledge, etc.), in a process of reciprocal learning and without hierarchy, for the resolution of certain complex problems. This interaction generates a new type of knowledge by integrating different disciplinary discourses and non-academic knowledge, through the methodological formulation of an ecology of knowledge that transcends the epistemological and methodological interface of all of them. It is the meta-point of encounter between the disciplines and the conception 'between, through and beyond the disciplines'. Its main objective is to achieve the unity and unification of knowledge.

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As can be seen in the different figures (1, 2, 3, 4, and 5), in recent decades, knowledge has been organized through new theoretical and methodological approaches that allow us to approach the complex network of social and natural phenomena that constitute our ontological and perceptive reality. Thanks to these approaches, the options for framing the inter-retro-actions between neuroscience and education can be better understood. The neuroscientist Damasio (2010) points out that our actions are preceded by neuronal electrochemical impulses caused by the emotional feelings and thoughts that arise from our interiority. That is why we can conclude that we externalize what is inside us, and vice versa, since we internalize what happens outside. This complex process of inter-retro-constant actions between subjects and the socio-ecological environment is an important feature in the coevolution of living systems. The non-linear understanding of this emotional order-disorder of our inner-outer universe is fundamental for those who work with education, since it implies recognizing the teaching-learning processes as the effective result achieved by individuals - complex adaptive systems - in intermediate conditions of order and disorder. Placing the educational processes in the context of the complexity that characterizes the production of knowledge in the 21st century, requires, among other aspects, the incorporation of the biological dimension that underlies teaching and academic learning. For this incorporation to be effective, it is necessary to establish a defined epistemological framework that makes it possible to achieve the goal of synergy between the sciences of the brain, the mind and education.

The bridges between brain, mind and education

As indicated by Carroll *et al.* (1984), the question of achieving a closer link between cognitive research and educational praxis is addressed in a report by the National Academy of Education, which points out the advances in studies on cognition as one of the driving forces to work educational innovation processes. Along the same lines and focused on the research carried out by cognitive neuroscience, the reports prepared by organizations such as the OECD (2002, 2007), The Royal Society (2011) and UNESCO (2013) were developed. Despite the efforts made by different social, political and academic bodies for the consolidation and development of the proposal of consilience between the sciences of the brain and education, this area of knowledge still reflects a marked disparity between the prolif-

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eration of susceptible neuroscientific studies of application to education, and the limited influence exerted within educational settings.

Gibbons *et al.* (1994) believe that this dichotomy could be reflecting, in the first instance, the need to evolve epistemologically from interdisciplinary frameworks for research and knowledge generation, to genuinely transdisciplinary ones. This evolution requires the overcoming of the modes of traditional knowledge production, where the problems are posed and solved in a context governed by the academic interests that underlie each discipline. The creation of a research space that communicates to the neuroscience laboratory with the classroom requires a deep re-conception of the disciplinary limits. The consolidation of an effective transdisciplinarity would allow the opening of new approaches that would make possible the synergy between the different involved disciplinary discourses. Davis and Phelps (2005) indicate that the disciplinary discourse results in a structurally coherent domain of the use of language, which organizes and delimits what can be said, done, thought and, therefore, also known. This discourse always works in relation to, or in opposition to, other discourses. It is when there is a definite opposition that interdiscursive practice or dialogue with those other discourses involved is more relevant, in order to make possible the survival of the new field of knowledge.

The need to create an interdiscursive space where to position the attempt of convergence between neuroscience and education was reflected through an intense debate between those positions that postulated in favor of the impossibility of a line of direct communication between both disciplines, and those other who positioned themselves in a diametrically opposite position. The academic debate lasted throughout the last decade of the twentieth century, persisting to this day. It is often expressed in the literature associated with this topic through the metaphor of the Bridge or way of communication between disciplines. In this sense, exposes Bruer (1997), the allusions to bridges are too distant; bridges over turbulent waters according to Ansari and Coch (2006); the establishment of communication channels according to Varma, McCandliss and Schwartz (2008); the need for the establishment of bridges according to Mason (2009); the construction of interactive bridges according to Benarós *et al.* (2010), and the arrival of the moment to build the bridge between neuroscience and education according to Sigman *et al.* (2014). Under a dialectical perspective, the development of this new field could be conceived as a product of the synthesis between those theses rooted in an exaggerated optimism, deriving in educational approaches based on erroneous and

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non-rigorous interpretations of neuroscientific research, such as the paradigm known as *Brain-Based Learning*, or the educational neuromyths studied by Howard-Jones (2014) and the OECD (2002, 2007).

As expressed by Bruer (1997) and Willingham (2009), this type of academic approaches led to the emergence of those antithesis or counterarguments that postulated in favor of the inconvenience of a direct application of the results of research in neuroscience to the educational field. Dekker, Lee and Howard-Jones (2012) indicate that at the core of this debate emerged the proposals that tried to synthesize both positions, promoting the approach of fundamental issues around the process of demarcation of disciplinary boundaries. The synergy between education and neuroscience requires the convergence between educational research, rooted in the context of the social sciences, and neuroscientific research rooted in the context of the biological sciences. The natural link between these two disciplines is guided by the object of shared study: human learning.

From an inclusive point of view, the framework of this convergence between epistemologically remote areas can be extended to all those disciplines linked through the nexus of the study of learning: the learning sciences. Learning is emerging as one of the keys to human progress. Lim (2016) points out that the knowledge generated through the multidisciplinary structure known as learning sciences does not usually enable the emergence of deep and holistic ways of understanding, capable of reflecting all the inherent complexity of learning as an object of study. Wilson (1998) alludes to the fact that the main goal of all types of consilience between disciplines is to achieve intellectual unity or unity of knowledge. The need to generate unity of knowledge regarding the different dimensions in which human learning is framed, and the integration of mental and neural levels, has been satisfied through the emergence of cognitive neuroscience through the process of disciplinary hybridization between cognitive psychology and neuroscience. This disciplinary space, in which the neural and mental levels are addressed in an integrated manner, was baptized by the OECD (2007) as the birth of a new science of learning.

Since the entrance of cognitive neuroscience in the area of studies on learning, the generation of educational knowledge revealed the need for an update or rethinking in the communication between the fields of study of cognition, education and learning (reflecting this effective integration between the sciences of the mind and the brain). Vivas (2015) indicates that both teaching and learning constitute the nuclei of educational teleology, expressing in this way the dialectical relationship established between those who teach and those who learn. In this sense, Songer and Kali (2014) resort

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to the coevolutionary metaphor to describe the type of relationship between education and the learning sciences. Coevolution, from the biological point of view, describes the process of synchronic changes over time in two different species that result in a strong mutually beneficial relationship. Collado (2016a) defines coevolution as "a reciprocal evolutionary change between species and their natural environment that, during the complex development of inter-retro-actions among themselves, modify each other constantly" (p.58). In general terms, coevolution is a phenomenon of feedback very present in nature and serves as a basis to better understand human learning in its social, cultural and educational context.

The coevolutionary metaphor applied to education highlights the place it occupies within the processes of human learning. School education is one of the privileged scenarios in which human learning takes place, and learning is emerging as one of the main objectives of teaching. Teaching and learning are, therefore, the educational binomial par excellence. Therefore, it is natural that the communication and influence between the disciplines dedicated to the study of both topics occur in a fluid way and with a strongly marked character of interrelation.

During the process of evolution in the study of human learning it required the construction of bridges between mind and education, consolidated through the discipline of educational psychology, but also those other bridges between mind and brain established in the development process of cognitive neuroscience. The need to establish a closer relationship between studies on cognition and education is collected by Puebla and Talma (2011), since as Fischer, Goswami and Geake (2010), or Pérez (2012) indicate, the incorporation into the educational context of the results of neuroscience research would help to open the black box to where the biological and cognitive processes that underlie learning have been relegated. However, this incorporation is not yet epistemologically defined. In its consolidation, interdisciplinary and transdisciplinary approaches have been explored, reflected in the evolution of different nomenclatures used in the literature associated with the topic of neuroscience and education: neuroeducation, educational neuroscience and mind, brain and education.

Terminological questions about neuroeducation, educational neuroscience, and mind, brain and education

The term neuroeducation emerges in the academic context in a work by Odell (1981), to allude to the need to search for educational strategies

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compatible with the brain. Neuroeducation is defined later by Battro and Cardinali (1996), who coin the term in the Spanish language, defining it as the use of scientific research for the confirmation of the best pedagogical practices. Neuroeducation constitutes a new interdiscipline aimed at promoting greater integration between the sciences of education with those dealing with human neurocognitive development. Its primary objective, as Ansari, De Smedt and Grabner (2012) suggest, is not to introduce radical changes in the context of curricular content, but to provide a renewed vision that emphasizes the development of cognitive abilities that can be used transversally in the different areas of knowledge that make up the curricular structure. Neuroeducation refers to the provision of a scientific sustenance for the art of teaching, constituting itself in the form of an emerging discipline rooted in the interaction between the studies of the mind, the brain and education; making possible, according to Carew and Magsamen (2010) or Tokuhama-Espinosa (2008) new ways to face the challenges presented by the education of the 21st century. According to Pasquinelli (2012), neuroeducation is a recent approach in which to face the challenges presented by current educational policies, emphasizing the need to face the dual objective of devising new effective educational methods and facilitating understanding around their own effectiveness.

Neuroeducation has an implicit relationship with another one of the proposals that emerged within the convergence of cognitive sciences and education, the mind, brain and education project (MBE). Tokuhama-Espinosa (2010) describes the MBE project as the intersection between the fields of knowledge of neurology, pedagogy and psychology, establishing neuroeducation as one of its branches and characterizing it based on the use of empirical scientific research as a method to confirm the best pedagogical practices. The MBE proposal, as Battro, Fischer and Lena (2008) report, originates through the process of updating teacher training at Harvard University, picking up the collaborative project between various academic areas, such as biology, genetics or psychology in relation to their contributions to the construction of pedagogical knowledge. This project of disciplinary collaboration led to the emergence of a new transdisciplinary area where the fields of neuroscience and education would have prevalence. The term MBE, according to Ferrari and McBride (2011) or Tokuhama Espinosa (2011, 2015) evolves from a category similar to neuroeducation to another that places it as the matrix of the transdisciplinary approach in which the *science of the mind, the brain and the education are supported.*

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Finally, the third nomenclature refers to the term educational neuroscience. Szucs and Goswami (2007) define it as a combination between cognitive neuroscience and behavioral methodology for the investigation of the development of mental representations. Lalancette and Campbell (2012) indicate that it occupies the space of intersection between neuroscience, cognitive science and education. Geake (2009) places it within cognitive neuroscience, as a subdiscipline oriented towards the investigation of cognition processes linked to educational contexts. Campbell (2011) conceives it as a branch of cognitive neuroscience applied to education. Battro, Fischer and Lena (2010) define as complementary the fields of knowledge of neuroeducation and educational neuroscience, emphasizing each of the approaches: neuroeducation emphasizes the educational focus of the connection (relevance of neuroscience for education), while in educational neuroscience the focus falls on those areas of neuroscience connected with the educational field (relevance of education for neuroscience).

In conclusion, it could be said that both neuroeducation, MBE, and educational neuroscience share a common basis in which the relationship between neuroscience and education is emphasized. MBE could be placed as the transdisciplinary root from which emerge two interdisciplines, neuroeducation and educational neuroscience. However, it should be noted that Beauchamp and Beauchamp (2013) emphasize that, despite this differential view, that the terms are used in many publications as synonyms, and that the use criterion is linked to the specific academic environments in which the respective research proposals are carried out. In this regard, the three proposals are closely linked to the academic context. The disciplinary proposal of the educational neuroscience finds the propitious spaces for its consolidation in the Center for the Neuroscience in the Education of the University of Cambridge, established in the year 2005. Three years later, during 2008, the Center for Educational Neuroscience of the Universities of Birbeck and London was created. Neuroeducation is consolidated with its own identity in a parallel proposal with a center at the University of Bristol, through the Center for the Mind and the Brain in social and educational contexts created in 2005. Finally, and from its origins, MBE is a project closely linked to Harvard University. In 2004, the creation of the International Mind, Brain and Education Society took place, with the appearance of the editorial product associated with this research line, Mind, Brain and Education Journal. In the year 2005 the international extension in Italy, the International School of Mind Brain and Education opens.

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Neuroscience and education: the interdisciplinary approach

The connection between the different terminologies and the epistemological aspects is reflected in the corpus of associated literature, and it can be observed that neuroeducation is frequently characterized as the result of an interdisciplinary work effort, according to Ansari, De Smedt, and Grabner (2012), Hook and Farah (2013), Nouri (2013, 2016) or Pallarés (2015), although there are exceptions that fit within a transdisciplinary framework as in the case of Howard-Jones *et al.* (2015). MBE is emerging as the project most linked to transdisciplinarity as expressed by Della Sala and Anderson (2012), Fischer (2009), Knox (2016) or Özdoğru (2014). In turn, educational neuroscience is conceived in some works as an interdisciplinary as in the case of Fischer, Goswami and Geake (2010), Geake (2009), McCandliss (2010), Szucs and Goswami (2007) or Palghat, Lodge and Horvarth (2017); while in others in which the term appears explicitly as synonymous with MBE, it is characterized as a transdiscipline as indicated by Flobakk (2015, 2017), Patten and Campbell (2011) or Summak, Summak and Summak (2010). It could be affirmed, therefore, that the different disciplinary products arising around the topic of neuroscience and education pass through an epistemological continuum located between the inter- and transdisciplinary spaces. The consequences of the positioning in one or another axis of the continuum correspond to modes of production of different knowledge and, therefore, to the nature of the knowledge resulting from each of the approaches, together with its conception of the boundaries between disciplines.

Framing the result of the convergence between neuroscience and education in an interdisciplinary or transdisciplinary framework implies starting from different principles and objectives in the process of building the bridges that communicate the different areas of knowledge. As emphasized by Smirnov and Bottomore (1983), in the process of interdisciplinary construction, collaboration between the different disciplines is built on the basis of conceptual and methodological materials specific to each disciplinary territory. This collaboration continues to respect the disciplinary limits, as reflected in the conceptions that place educational neuroscience as an interdisciplinary product. Campbell (2011) collects this fact by calling it a restricted conception of educational neuroscience that places it as a cognitive neuroscience applied to education. From this academic view, educational neuroscience is constituted as an ontological and epistemologically interdisciplinary discipline located at the center of

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the convergence between the sciences of the mind and the brain. Methodologically it is ascribed within the methods that characterize cognitive neuroscience, encompassing all those neuroimaging studies related to research on neurocognitive development (both typical and atypical), and those aspects most relevant to educational learning processes.

By establishing interdisciplinary communication channels between neuroscience and education, the contributions of educational psychology are complemented, introducing a new level of analysis. According to Burunat and Arnay (1987), this *channel allows the arrival of the brain* to the construction of educational knowledge. The type of knowledge generated through this interdisciplinary framework is integrated into the construct of the learning sciences, assuming an update based on the incorporation of the neural level in the construction of knowledge. The connection with the educational field is implicitly delimited, requiring the collaboration of the educational actors for the processes of application of the results arising in the environment of the neuroscience laboratory. This type of approach would solve, at least in part, the question of the link between neuroscience and education, but it would leave in the air the question about the solvency of the disciplinary relationship in an inverse sense, that is to say, the communication between education and neuroscience. In the interdisciplinary model, therefore, the traditional unidirectional communication approach remains in place, placing research emerging within the learning sciences as a source of key information for the educational context. The questions associated with the other side of the bridge emerge at this point of the interdisciplinary journey: the educational one. If within the neuroscience-education binomial the emphasis is transferred to the second term, we could situate ourselves in the reverse version of the dialogue, which communicates education and neuroscience. This could facilitate the possibility of addressing the shortcomings and problems evidenced in the criticism that Bowers (2016) makes to this new field: the absence of a real influence of the research carried out in the field of new interdisciplines to the classroom scenario.

Education and neuroscience: the transdisciplinary approach

Tracing the origin of the differentiation of the terms inter- and transdiscplinar from an etymological perspective, the root of discipline is associated with the lexicon of Latin origin -*discere*- which means to learn,

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while the suffix *-ine* indicates belonging. In this way, the term discipline refers to the belonging to a field of learning, susceptible to be expanded by the use of different prefixes. The prefix inter- alludes to the occupation of those spaces that arise between the disciplinary connections, while the prefix trans- indicates the adoption of an approach characterized by being in, between and beyond the disciplines conceived as a construct with defined limits in those that frame the management of knowledge.

From a historical perspective, the transdisciplinary term emerged in the 70s with a direct link to the educational issue and the need to overcome the monodisciplinary approach in teacher training. The lack of a synergy between the science of current learning during the second half of the twentieth century (psychology) and educational science (pedagogy), has been collected by Bernstein (2015), Nicolescu (2010), McGregor (2014) or Petts, Owens and Bulkely (2008), agreeing on the relevance of their coping within an International Conference on Interdisciplinarity University Education: Problems of Teaching and Research in Universities, sponsored by the Minister of Education of France, the University of Nice and the OECD. Within this historical and academic context, the transdisciplinary term was defined by Piaget (1972) as a superior state of interdisciplinary approach, which would come to cover not only interaction or reciprocity relations between specialized research projects, but also place these same relationships within a total system without firm disciplinary boundaries. According to Jantsch (1972) and Lichnerowicz (1972), transdisciplinarity responded to the process of coordination of all the disciplines and interdisciplines of the innovation and teaching system on the basis of a general axiomatic approach, emphasizing the homogeneity character of the theoretical activity in the different sciences and diverse techniques, independently of the scope where this activity takes place.

In this sense, transdisciplinarity is a recent epistemological and methodological approach. It arises in the academic context to respond to the increasing levels of complexity of the problems posed by the real world, and, more specifically, those issues that are required to create a vision that transcends the boundaries between disciplines. The ability to overcome limited visions in traditional disciplinary frameworks is what enables the generation of areas of knowledge that operate under logical principles different from traditional disciplines. In his famous book *Manifesto of Trasdisciplinarity*, Nicolescu (1996) introduced three epistemic pillars for transdisciplinary research: the levels of reality, the logic of the included third and complexity. This epistemic conception seeks to overcome dichotomous, reducing and hyperspecialized thinking, in order to

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integrate and include different types of non-scientific knowledge. While there are different physical laws that govern each ontological level of Nature (macro, meso and micro), our human perception also has different levels to understand our reality. In this sense, the Logic of the Included Third developed by Lupasco (1994) acts by integrating different elements and phenomena with a polyplogical approach. This means different logics acting together in the same space-time, despite the contradictions.

Bergman *et al.* (2005) indicate that this type of inclusive logic operates through those investigations that face a complex phenomenon, which require overcoming the disciplinary limits and the development of appropriate methods for the integration of a segmented and fragmented knowledge through the different scientific fields. Hadorn *et al.* (2008) allude to the fact that one of the intellectual reasons for the transgression of the boundaries between disciplines is the need to integrate different perspectives, added to the search for innovation in the fundamental scientific understanding of specific problems. Benarós *et al.* (2010) include the possibility of integrating the three levels of reality analysis in the study of human development and learning. Thus, the integration of the biological, cognitive and behavioral level of the same ontological core requires the overcoming of the epistemological gaps opened in each of the levels. In this sense, the proposal of convergence between the sciences of the mind, the brain and education, is emerging as a generator of complex knowledge; in the sense that encompass all those phenomena that are woven together. In this line of thought, Morin (1999) expresses the need to integrate levels of brain, cultural and mental studies, in order to adopt complex thought patterns in the construction of educational knowledge.

Koizumi (2004) emphasizes that we must transcend those inter- and multidisciplinary perspectives for the establishment of a transdiscipline where neuroscience and education can meet. The transdisciplinarity would enable the creation of a new epistemological field with its own conceptual structures, through the fusion of the limits of different disciplines. According to Samuels (2009), the connecting link in a transdiscipline does not reside in the adoption of a common theoretical, epistemological or methodological perspective, but in the objective of achieving a deeper and holistic and integrating understanding of a shared object of study. In this process of generation of transdisciplinary knowledge, the actors of each of the disciplines make their contributions from the level of reality studied in each field of knowledge, offering a product in which the different dimensions of the phenomenon become integrated.

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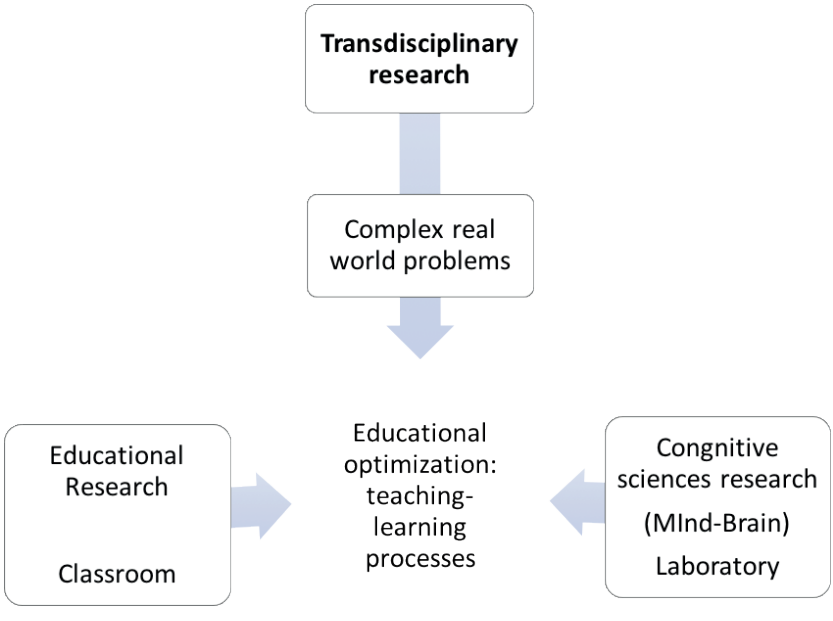
The transdisciplinary research model seeks to overcome the interdisciplinary level, characterized by placing neuroscience as one of the sources of information of possible relevance to the educational field in the context of a unidirectional communicative relationship. In the process of theoretical development of mind-brain-education, the need arises to adopt a transdisciplinary approach, in order to create a bidirectional influence structure between the integrating areas. This perspective was picked up as a priority by authors such as Della Chiesa, Christoph and Hinton (2009), Knox (2016) or Koizumi (2004). Beyond integrating neuroscience as a new discipline within the learning sciences, Tokuhama-Espinosa (2011) states that the MBE Project implies the creation of a new science of teaching and learning, within a transdisciplinary space, whose development could offer, as a result, new ways of considering old educational problems. According to Fischer (2009), the field of MBE pursues the goal of effective integration between research and practice, in a solid infrastructure that unites the efforts of scientists and educators to enable an effective study of teaching-learning carried out in the educational scenario (figure 6).

Figure 6
Transdisciplinary research



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As seen in Figure 6, the adoption of a transdisciplinary model in the question of linking neuroscience and education entails the introduction of a dynamic of influence between both fields. In this sense, Mason (2009) expresses that here emerges the opening of a bidirectional way where the scenarios of the classroom and the cognitive laboratory operate in a joint way. On an epistemological level, Gibbons *et al.* (1994) point out that transdisciplinarity is linked to new heteregeneous and heteroarchaeological modes of production of knowledge, where the sciences of the mind, the brain and education converge as disciplinary areas with a shared and systematized object of study among the different academic fields. The creation of a transdisciplinary space allows the integration of research resulting from the intersection between the laboratory and the classroom, in order to be effectively captured in the real world. Bergman *et al.* (2005) indicate that in this approach, on the one hand, it is possible to work on a first level where a synthesis of the modular results is sought from an inclusive and integrating perspective that collects the totality of the problems worked on; while on the other hand they are able to face the challenges of a second level, equating the emphasis on the development of relevant results in the scientific field to the results relevant to the practice.

In addition, the transdisciplinary approach would also make it possible to overcome the pitfall of introducing classroom practice in the product of collaboration between disciplines, and therefore, the collaboration of a non-academic actor in the production of scientific knowledge: the teacher. In this aspect, the proposal of a transdisciplinary research model converges with the critical theories of education of Giroux (1990) that denounce the isolation of teachers in the process of construction of educational knowledge and the reduction of teaching autonomy regarding the development and curriculum planning. Geake and Cooper (2003) point out that one of the advantages of the proposal of intersection between research in neuroscience and education lies in the reduction of the level of marginalization of teachers, as regards the contributions on the construction of pedagogical theories, based on their direct knowledge of the reality of the classroom. In turn, Vidal (2008) frames the teaching role within the bidirectional relationship that requires the development of the new transdiscipline, enabling the arrival of cognitive neuroscience contributions to the classroom; but contributing, at the same time, so that their reflections and opinions about the application of these contributions can reach the neuroscience laboratory.

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Conclusions

"The world has problems, but universities have departments" (Brewer, 1999, p 328).

The process of linkage between neuroscience and education has led to a proliferation of literature associated with the topic, where the evolution and development of the creation of a new area of knowledge can be analyzed; product of the contact between both fields of study. From an ontological point of view, the educational perspective could be considered much more complex than that positioned within the biological framework of neuroscience. According to Ortega and Fernández (2014), the ontological framework of education covers the entire process of building the human being. In this regard, and after the literature process, it was observed that the denial of intrinsic reductionism to an approach to the study object of education based exclusively on the neural level would be a vain attempt to place the contributions of neuroscience within of the educational field. However, the denial of the need to incorporate this level could be, in the same way, a clear detriment in the confrontation of the complexity inherent in educational praxis and theory. Education is an extremely complex phenomenon that requires transcending the analysis centered on the neural levels of the teaching-learning processes. It should be noted, however, that without an effective incorporation of the biological level into the construction of educational knowledge, education would be denying itself the opportunity to collect the possibilities of optimization and innovation raised from the neuroscience laboratory.

The recognition of the multidimensionality that underlies this ontological complexity highlights the need to integrate the different levels from which the human being can be studied in reference to his position as an educational subject, an active agent of learning and a provider of meaning to processes teaching. For this reason, the incorporation of neuroscience to the construction of educational knowledge should not be conceived as a panacea nor as the only support or foundation for a new *educational revolution.* This type of approach characterized by a naïve enthusiasm and based on non-systematized approaches and without the rigor necessary to establish the basis of disciplinary communication, gave rise to the emergence of an authentic neuromitology within the teaching community, as well as the paradigm of *Learning Based on the Brain.*

In this regard, it is also worth noting that the reports issued by different official bodies, involved in the design and implementation of educational policies, have recognized the urgent need to build bridges

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between neuroscience and education. These communication channels between both areas, solidly anchored in the principles governing the production of scientific and academic knowledge, constitute the best alternative for the eradication of misunderstandings and misinterpretations regarding the influence potential of neuroscience in the educational field.

In addition, and as it has been collected throughout this work, in the current state of the issue and its epistemic dimension, Bravo (2007) expresses the need to reconsider the traditional ways in which it has been framed the study of the human being as an educational subject, in order to redifine education in a way that can respond to the current challenges demanded by 21st century society. In this line, it is observed that one of the transversal topics of the reviewed literature is how the challenges and problems of the educational world at the beginning of this 21st century could be needing solutions that transcend the departmental models in which educational research is framed. In the specific case of neuroscience and education, the contributions regarding neuroplasticity, or regarding the intricate interrelation between the cognitive and emotional aspects that determine success and failure at school, constitute phenomena of great relevance, and that despite constituting central nuclei of cognitive research have barely found an answer in the educational environment.

The causes or reasons for the disparity in the attempts of disciplinary convergence between neuroscience and education could be traced to the inconcretion of its terminology and to the epistemological ambiguity present in each of the current nomenclatures. In the neuroscience-education binomial, education seems to remain absent. According to Zadina (2015), both skepticism and competitiveness between the areas of the mind, brain and education sciences involved, have led to a debate in which psychology and neuroscience dispute the suitability to inform the field education establishing unidirectional channels of dialogue. This unidirectional way has fostered the synergy between cognitive psychology and neuroscience in its specialized aspect in educational learning. Through the interdisciplinary model in which the academic products resulting from the encounter between neuroscience and education seem to be settling (or what has been termed as a reduced vision of educational neuroscience), a prolific body of research has been brought to light, which based on neuroimaging techniques, provide solid evidence on the neural processes that underlie school learning and the educational capacity to influence these same processes. However, despite the abundance of scientific literature in this field, the theory and educational praxis seem to remain impervious to this type of evidence.

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Educational neuroscience, understood from the interdisciplinary paradigm, could be defined as a subdiscipline of cognitive neuroscience or, in other words, as a mind-brain binomial in which the triangulation required by the intellectuals of the field would still require an opening of the third element in play, the educational one. For this inclusion and integration to be effective, numerous literary studies indicate that the adoption of a transdisciplinary framework could be one of the key tools to be able to fit the processes of interrelation between the involved areas of knowledge. This interrelation must be expressed through new ways of dealing with the construction of theories and research in the field. The construction of educational knowledge, although it can be enriched by neuroscience neuroimaging methodologies, necessarily requires educational research, as well as its concretion in the classroom setting, when it is conceived as the correlate of the laboratory scenarios of the cognitive sciences.

In summary, it is known that the fact that teacher education is a key element for the future of transdisciplinarity. That is why Rosenfield (1992) argues that each member of the transdisciplinary team needs to be sufficiently familiar with the concepts and approaches of the rest of the team members to be able to carry out the blurring of the disciplinary limits, allowing the coping of the common problems as part of a wider phenomenon. Coch and Ansari (2009) also reflect on this fact, pointing to the need to include basic contents of neuroscience in teacher training. Through an update in the education of educators that incorporates the contributions of neuroscience, added to the effort for the development, during the process of training, of a solid investigative competence, the entry of a new actor in the transdisciplinary proposal could be propitiated, in the form of a teacher-researcher. This new teacher profile could occupy the ideal place to establish a multireferential dialogue with the cognitive laboratory in the correlate of the classroom. The teaching claim of the place that belongs to him by right: the classroom, in its investigative dimension, could enable the triangulation that the transdisciplinary field of mind-brain-education research requires, helping to consolidate a new paradigm of transdisciplinary educational research.

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