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WHAT DO WE KNOW ABOUT THE TEACHING BRAIN? A LITERATURE REVIEW

CHE COSA SAPPIAMO DELLA RELAZIONE TRA CERVELLO E INSEGNAMENTO? UNA REVISIONE DELLA LETTERATURA

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Abstract

Several contributions have emerged from the research field in the sphere of experiences on Brain-Based Education and Neuroeducation models, while we have less evidence on the topic of the Teaching Brain. It is a concept that reflects the complex, dynamic and context-dependent nature of the learning brain. The assumptions underlying this construct suggest that by studying the teacher's brain, classroom work with students can be improved. Starting with an exploratory review of the international literature on research related to the Teaching brain, we focus on the functions of the teacher's brain and the implications it may have on the teaching-learning relationship and teaching practices. The Teaching Brain perspective implies the possibility that knowledge from these studies can help teachers in their work with students in the classroom, through different pedagogical choices. It is an under-explored and critical research topic, which may foster new reflections on teaching and interaction in educational processes.

Numerosi sono i contributi che stanno emergendo sia dall'ambito delle ricerche, sia dall'ambito delle esperienze sui modelli di *Brain-Based Education e Neuroeducation*, meno abbiamo evidenze sul tema del *Teaching Brain*. È un concetto che riflette la natura complessa, dinamica e dipendente dal contesto e dal cervello di chi insegna e anche di chi apprende. Le ipotesi sottese a questo costrutto indicano che studiando il cervello dell'insegnante, si possa anche migliorare il lavoro in classe con gli studenti. Partendo da una revisione esplorativa della letteratura a livello internazionale, ci si sofferma sulle funzioni del cervello dell'insegnante e le implicazioni che può avere nella relazione di insegnamento-apprendimento e sulle pratiche didattiche. La prospettiva *Teaching Brain* sottende l'eventualità che le conoscenze derivanti da questi studi possano aiutare gli insegnanti nel lavoro in classe con gli studenti anche attraverso opportune e mirate scelte pedagogiche. È uno tema di ricerca ancora poco esplorato e critico, che può favorire nuove riflessioni sulla didattica e sull'interazione nei processi educativi.

Keywords
Teaching Brain; Educational Neuroscience; Neuroeducation;
Didattica e cervello, Educazione e Neuroscienze, Neurodidattica

Supporting neuroscience in educational knowledge. An ongoing epistemological debate

Recent breakthroughs in neuroscience have moved brain research to the hub of learning science and created new opportunities for education policy makers and practitioners. Neuroscience does not provide direct answers for practical problems in education, on the contrary, existing inconsistencies in the research findings may mislead educators. Science is an evolving field and its translation into the classroom can lead to some contradictory interpretations and applications.

The idea that data and neuroscientific research can inform education theories and practices is not new (Iran-Nejad, Hidi & Wittrock, 1992; Jensen, 2005; Willingham, Lloyd, 2007). In the last two decades, researchers have gained greater understanding about how the brain learns. This knowledge has supported the development of new academic disciplines, namely: educational neuroscience, neuroeducation and mind, brain and education. This recent field of study utilizes the results of research in neuroscience, education and psychology, broadening teaching and learning (Battro 2007, 2010; Fisher 2009; Fisher & Daniel 2009; Fisher et al, 2007; Busso, Pollack, 2014; Howard-Jones, Yau, 2018; Immordino-Yang, 2013; Strauss, 2005; Tibke, 2019). Educational neuroscience aims to reflect research results and verify the potential impact on educational practices. This interdisciplinary approach assures that the proposed solicitations have a solid basis of scientific research so teachers can facilitate the implementation of new educational approaches (Sousa, 2011).

However, objections to the cited studies posit that neuroscience is not able to influence the practice-based sphere of education. Meirieu (2018), in fact, argues that neurosciences cannot change the classroom setting, rather the neuroscientific approach can demystify brain activity, but not impact on the content taught in classrooms. The provocation of the French philosopher (similar to an editorial in Nature, 2005; Bruer, Bowers, 2016, Krammer, Vogel, Grabner, 2021) finds its antithesis in several recent studies that converge on the significance of the interaction between neuroscience and education. Recent breakthroughs in neuroscience have moved brain research into the sphere of learning sciences and have created new opportunities for education policy makers and practitioners (Fisher, Goswami & Geake, 2010).

However, neuroscience does not provide direct answers for practical problems in education, on the contrary, existing inconsistencies in research findings may mislead educators.

Practical collaboration at the intersection of education and neuroscience research is difficult because the combined discipline encompasses both the activity of microscopic neurons and the complex social interactions of teachers and students in a classroom (Colvin, 2018).

Science is an evolving field and its translation into the classroom can lead to some contradictory interpretations and applications. In the conclusions of their study, Summak et al (2010) declared the need to provide the transdisciplinary bases for remedial and individual-specific educational programs beyond the current boundaries of education, and to produce a new breed of professionals (neuroeducators) who are able to transfer scientific findings from cognitive and neuroscience to schools, as a first-hand provider of joint research (Ansari, 2005; Edelenbosch et al, 2015; Geake, 2009; Goswami, 2004; Howard-Jonas, 2014; Knox, 2019). There is much data on the neural correlates of learning, including Williams et al (2017), who also found specific neuro patterns correlated to the successful learning of real-world context. Research shows that neuroimages are persuasive for both educators and the public. When faced with complex, unfamiliar information, individuals tend to use a reductionist structure to reduce psychological phenomena to their lower-level neuroscientific counterparts. In addition, neuroscience is associated with powerful visual imagery, which tends to make scientific claims more convincing. This has far-reaching implications for both teacher education and professional development. Bridging education and the neurosciences is complex, with various steps connecting the two disciplines. A model of this path is presented in Tommerdahl (2010). Five basic levels are offered in the model: neuroscience, cognitive neuroscience, psychological mechanisms, educational theory and, finally, the classroom. For effective teaching methods that are based on neuroscientific findings, and are supported by a scientific evidence base, most or all of these levels of work, and possibly more in some cases, are necessary to their development. The translation of these neuroscientific insights into classroom teaching practice has been very limited (Morris, Sah, 2006). The neural mechanisms that support naturalistic learning and teaching remain still elusive.

Concerns raised about the possibility that the contributions of neuroeducation research might also offer indications and strategies for educational and teaching practices, also require continuous reflection at the pedagogical level. The dialogue between pedagogy, learning, teaching and neuroscience is widely covered (Santoianni 2019; Author 2020; 2021), but it requires constant stimulation and scientific input at multiple levels.

In science, while anchoring oneself to one's own paradigms allows for coherence, clarity and epistemological linearity, it also sometimes risks becoming a closure to the pursuit of new issues and new paths. There are several international contexts that advocate an interdisciplinary approach to scientific research, where, to quote Santoianni (2019, p.45), none of the disciplinary fields involved is called upon to relinquish its epistemological identity, mutual contamination does not mean relinquishing disciplinary distinctiveness. It goes without saying, therefore, that neuroscience and education, biology and cognitive science, while maintaining a rigorous epistemological link within their own boundaries, can interact in understanding the role of mind and brain in learning and teaching processes, offering new contributions, perhaps even challenging in their nature for the future, these knowledge disciplines share some common constructs: the active construction of knowledge as the focal point of learning processes, but also of teaching, dynamic learning processes, dependent on the context, cognitive, emotional, interactive. Also in the *Teaching Brain* approach these dimensions can be found and nourished.

1. Teaching and the Brain. Are there neural correlations?

The bidirectional relationship between learning and the brain suggests that some teaching practices may be more compatible with the pre-existing architecture of the brain and could lead to more efficient learning (Dehaene, 2008; Masson & Brault Foisy, 2014). In the recent review on teaching practice on the brain (Brault Foisy et al. 2020), the teachers can be thought of as "orchestrators" of neuronal plasticity, where the idea that the pedagogical choices that they make can impact how we learn and retain information. Neuroscience can provide both unique and complementary insights into children's learning and instruction (Id, 2020).

Despite the evidence that emerged from these studies in the literature, the effectiveness of this brain-to-brain coupling in teacher-students has yet to be fully demonstrated.

2. Studying the brain of the teacher. The genesis

Several contributions are emerging from the field of research and the field of experience on *Brain-Based Education* models, while there is less evidence on the topic of the *Teaching Brain* (Author, 2020).

We summarise some of the theoretical positions underlying the *Teaching Brain*, without claiming to be exhaustive and referring to the numerous contributions in the context of educational neuroscience, not all of which have uniform meanings, but allow for different openings in neuroscientific and educational research (Author, 2021).

Fisher, Rose (1998) propose Dynamic Skill Theory (DST) based on the theory of skills and cognitive development. The theory provides an abstract representation of the skill structures that emerge in cognitive development, together with a set of transformation rules that relate these structures to each other. The structures and transformation rules would make it possible to explain and predict developmental sequences and synchronies across ages. It is an adaptable framework for analysing the learning process in various contexts and measuring changes in observed cognitive and emotional learning.

Caine, Caine (2006) elaborate the theoretical *framework* defined as *brain-based learning* (BBL), distinguishing a superficial level of learning from a meaningful one, the former based mainly on memory, the latter on the connections between the different knowledge possessed and previous experiences. This means, according to BBL, that learning takes place in contexts which guarantee the meaningfulness of the experience for the learner. This concept can already be found in various previous psycho-pedagogical theories such as meaningful learning, theories of implicit learning or the recent positions on deep learning. Zull (2002), based on neuroscientific research of the neocortex through the sensory area, defines the learning process with the term the *brained-learning cycle* (BL): the interpretation and management of information occurs through neuronal networks, which are then conceptualised and rationalised; rational thoughts from the frontal cortex are sent to the motor cortex, where they take the form of active experimentation and then action. This cycle of learning is repeated in the human brain by the reception of new stimuli that explain the former process. Once again, we are close, in terms of reflection, to pedagogical theories found in experiential learning and transformative learning and initiating a promising reflection on the field of study called experiential brain model.

3. "Teaching Brain" perspective. A literature review

Starting with a systematic review of the international literature on research related to the *Teaching Brain*, we focus on studies that have explored the topic of the teacher's brain and the interconnections it may have in the teaching-learning relationship and on teaching practices.

The research question, which guided the exploratory review, was to trace neuroscientific studies that have dealt with the *Teaching Brain* or even the teacher themself, with the aim of summarising related concepts and evidence. This review responded to the following research question: what are the conceptual and methodological issues in the research on teaching brain?

The literature review was designed following the process described by Petticrew and Roberts (2006; Moher et al. 2015), conducted by a single researcher. The steps involved were: review topic, identification of relevant studies, selection of studies, analysis of data, synthesis of results.

Studies were collected in the time interval between December 2019 and February 2021 by querying the following generalist databases (Science Direct, Web of Science, Wiley) and educational databases (including JSTOR, ERIC, EBSCO, PsycInfo).

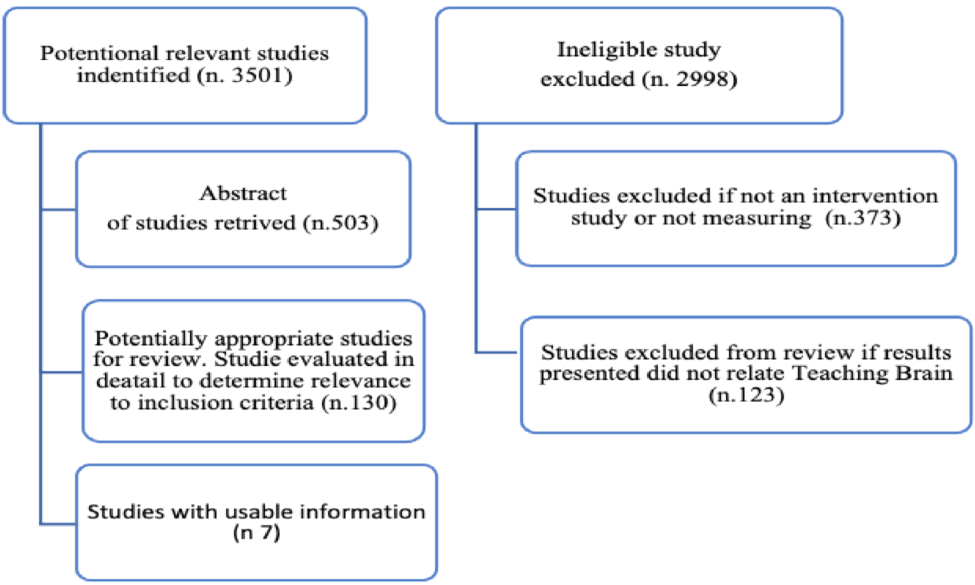

Figure 1 - Flowchart of databased searching

Studies considered were quantitative (e.g. randomised controlled trial; quasi-experiment; pre/post comparison; correlational). The literature review was limited to documents present in the databases in the period between 2000 and 2020 in English language (studies could have been carried out in any country, but reports had to have been written in English) and retrieved from the query using the following strings: Teaching and Brain: Teaching and Mind, Teaching and Neuroscience; and operating a selection of contributions in the field of educational research.

The next step in the selection of the literature was the exclusion of studies and research focusing on the learning brain, in order to focus exclusively on primary sources of a conceptual or empirical nature on the construct of teaching.

Steps	Description	N. articles	Justification
1	Specific records identified through database searching	3501	Inclusion criteria such as: peer reviewed only, 2000-2020 only, *descriptor linked to teaching AND brain*
2	Removal of irrelevant records	-2998	Exclusion criteria used: not relate in *educational and educational research;*
3	Removal of irrelevant records	-373	Exclusion criteria used: study if results presented did not relate *Teaching Brain*
4	Removal of irrelevant articles	-123	Exclusion criteria used: not *empirical study*
5	Studies included in the literature review	7	

Table 1 - Step of data sources

A total of 3,051 studies were identified, of which 503 pertained to educational and educational research, with an increasing trend from 2011 (39) to 2018 (64); 2998 studies were excluded because, after reviewing the abstracts, they clearly did not meet the criteria.

A total of 123 contributions of various kinds and types were identified, from which only documents with a specific focus on the *Teaching Brain* were selected, finally identifying 15 documents, of which 8 editorials/conceptual studies and only 7 empirical studies, on which the analysis was carried out (Fig.1; Tab.1; Tab.2), all studies were published articles in international scientific journals.

Study	Country	Participant	Research Design	Setting	Application/Outcome
Bevilacqua et al. (2019)	USA	12	Experimental study	Classroom-Lab	Cognitive Neuroscience
Brockington et al. (2018)	Brasil	4	Experimental study	Classroom	Cognitive Neuroscience
Davidesco et al. (2019)	USA	42	Experimental study	Classroom-Lab	Cognitive Neuroscience
Dikker et al. (2017)	USA	12	Experimental study	Classroom-Lab	Cognitive Neuroscience
Holper et al. (2013)	Switzerland	17	Experimental study	Lab	
Liu et al. (2019)	China	42	Experimental study	Lab	Cognitive Neuroscience
Pan et al. (2020)	China	24	Experimental study	Lab	Cognitive Neuroscience

Table 2 Included studies in the literature review and their characteristics

4. Implications of the “Teaching Brain” perspective for educational research

a. *Teaching Brain as awareness of teaching*

Among the studies on the *Teaching Brain*, those of Rodriguez (2013), highlight how the teacher’s brain is able to process learner-centred information, forming a theory of learner cognition that considers what the subject is thinking and the knowledge they would be able to acquire and accumulate. Teachers can, therefore, use this model to guide not only what the student is thinking and knowing, but also what he or she would be capable of.

Following in Fischer’s footsteps, Rodriguez considers teaching and learning as an interconnected system of dynamic skills. The teacher perceives learner-centred information, processes the information she has gathered that is relevant to learning and uses that information to respond, offering support to enhance learning processes. Rodriguez, Solis (2013) elected to adapt the Self-in-Relationships (SiR) interview to solicit and organize feedback from teachers about the underlying constructs of their teaching.

Results data suggest that a teacher’s awareness of interaction plays an important role within the teaching brain and, thus, the developing teaching brain framework (Rodriguez, 2013; Rodriguez, Fitzpatrick 2014).

b. *Teaching Brain as teacher-students interaction*

Few empirical studies have suggested that the interaction between instructor and learner is reflected in the extent to which brain activity becomes ‘coupled’ between them (Pam et al. 2020).

The neuroscientific research of Holper et. al. (2013) by Dikkers et al. (2017) and Liu et al (2018) try to identify markers, showing that the measures, the evidence reported by the brain studies solicit pedagogical variables arising in the student-teacher interaction. Using the technique of functional near-infrared spectroscopy (fNIRS), the research team examined the hemodynamic correlates during a specific teaching activity based on Socratic dialogue, as did the research of Goldin et al. (2011), which, however, focused on the learning brain.

Using the portable electroencephalogram (EEG) technique, Dikkers et al. (2017) conducted, attempting to detect the synchronic relationship between teachers and students with neuroscience by recording the brain activity of a group of students and the teacher simultaneously on several days during a semester while they were in the classroom. The results suggest that brain-brain synchrony is a sensitive marker that can predict dynamic interactions in the classroom and that this relationship can be driven by shared attention within the group.

Few studies have shown that interpersonal neural synchronisation can be a marker that can detect various interactions, including teacher activity during teaching action. Neural activities have been recorded during teaching actions, (similar to the research of Holper et al., 2013; Takeuchi et al., 2016; Zheng et al., 2018). In the research conducted by Liu et al. 2019, teacher-student interaction and student performance under conditions involving different states of cognition was studied, adopting the hyperscanning approach.

Bevilaqua et al 2019, Davidesco 2020, have recorded simultaneously students and their teacher during their usual high school biology lessons, which included both video and lecture components, and tested students’ retention post-lesson to capture the unique underlying neural activity of the social and behavioural factors in the class. Brockington et al. (2018) initiated a study directly in the classroom, attempting to detect the brain activity and physiological phenomena of students and teachers in the typical realistic scenario of the educational relationship in direct learning contexts.

Previous studies have suggested that the interaction between instructor and learner is reflected in the extent to which brain activity becomes ‘coupled’ between them (Bevilacqua et al., 2019; Holper et al., 2013; Pan et al. 2020). While some studies have shown such a relationship between brain-to-brain coupling and learning outcomes (e.g., Liu et al., 2019; Zheng et al., 2018), others did not in fact observe a correlation between teacher-student brain-to-brain coupling and content retention (e.g., Bevilacqua et al., 2019).

Pan et al. 2020, for example, have investigated the functional significance of brain-to- brain coupling in learning and instruction. In addition to examining whether brain-to-brain coupling between instructors and learners can predict learning outcomes, they asked whether brain-to-brain coupling can be used to classify instructional dynamics during interactive learning. They hypothesized that scaffolding-based learning would be associated with increased instructor-learner brain coupling compared to explanation-based learning. They observed an interaction between instructional strategy and instructional personalization in the superior temporal cortex (i.e., CH 25) at 0.17–0.27 Hz (F(1, 24) 1⁄4 13.49, FDR corrected $p < 0.05$). Average brain-to-brain coupling in prefrontal regions was positively correlated with learning outcomes in the scaffolding condition (r 1⁄4 0.65, uncorrected p 1⁄4 0.001) but not in the explanation condition (r 1⁄4 ‘ 0.24, uncorrected p 1⁄4 0.27), indicating that better learning was associated with stronger brain-to-brain coupling in the scaffolding condition alone (Id). Such a finding would suggest that brain-to-brain coupling may be a pedagogically informative implicit measure that tracks learning throughout ongoing dynamic instructor-learner interactions. In the Pan et al. 2020 study the evidence suggesting that, in real-life classroom teaching, constructive behaviours such as asking key questions and providing hints, promote information exchange and knowledge transfer between instructor-learner dyads and, consequently, learning outcomes. This interactive process, which is associated with an increase in instructor-learner coupling, is lacking when learners passively receive instructional explanations from instructors. Pan et al. 2020 suggestion that future studies combining the present two-brain approach with modelling techniques may help further elucidate the (computational and neural) mechanisms that e.g. distinguish scaffolding and explanation strategies during instructor-learner interactions.

5. A promising research direction?

Are there differences in the areas of brain activation of the teacher depending on the teaching strategy used during the classroom lesson?

The hypothesis is that, during a classroom lesson, there is a direct correlation between the activation of different brain areas and the application of specific teaching strategies (certainly not the only relationship); in particular, there seems to be a one-to-one correlation between the teacher's brain area and specific teaching strategies (a topic explored for example by Pan et al. 2020). Let us assume, in fact, that neural markers give different evidence when the teacher uses known versus less known teaching strategies. If the teacher feels more knowledgeable about a teaching strategy, she will be able to have different neural relationships. We hypothesise that markers inferred on certain areas of the brain (measured by neuroscientific metrics) in which there are changes in oxidative metabolism correlate with the type of teaching strategy and stimuli when subjects/teachers are teaching.

Neuroscientific evidence on the *Teaching Brain* can be interpreted as neural architectures, which infer or inform certain teacher behaviours and actions, directly related to teaching in real contexts such as the classroom. Do the findings also have implications for learning processes and students?

The *Teaching Brain* perspective suggests that we can support teachers by harnessing this approach to the study of teaching and education in general. It is not intended to outline a specific or rigid set of good practices, nor to offer a checklist that defines levels of good teaching. Indeed, the underlying assumption lies in the observation that each individual teacher takes responsibility for her own teaching, but the *Teaching Brain* framework can encourage both the analysis of postures and the results of neuroscientific evidence can allow us to read how neural architectures infer behaviours and actions that are also directly related to teaching in real contexts. Geake (2009; Rivoltella, 2012) insists on emphasising the importance of neuroscientific research for teaching, in a continuum between neuroscience and education, while also aiming to directly involve teachers in the task of defining the neuroscientific research agenda, which can also transfer scientific results from cognitive and neurological sciences to schools (Ansari, Coch, 2006).

6. Limitation

A scarcity of research available does not yet allow for a rigorous analysis, however, it shows that Few studies have yet been specifically concerned with a deeper understanding of the teacher's perspective according to the neuroscientific approach of the teaching brain.

One of the limitations of this study was the single researcher reviewer. Secondly, although we have tried to discuss some of the most important findings in the *Teaching Brain* literature, it is impossible to detail all emerging aspects in a limited space. The studies included in this review were carried out in English language, the possiblity for a culturally- related bias in the discussion of our conclusions should be acknowledged.

Conclusions

The interest in the state of the art of teaching neuroscience was prompted by the need to verify what approaches, methods and evidence are emerging on the Teaching Brain and whether scientific results can also contribute to improving understanding of teachers and their teaching styles.

The study presents an analysis based on the selection of a few international studies on the *Teaching Brain*. The *scoping review* shows that there are as yet few studies on the subject that strictly anchor the *Teaching Brain* at a neuroscientific level; it is a topic that has not yet been adequately covered, not least because of the difficulties in applying it to real-life contexts, but also because until now research has focused on the learner.

Studies show that certain neuroscientific markers make it possible to identify significant (exploratory) relationships.

They will also probably have an impact on educational and teaching practices, not least in order to change the approach to knowledge and learning processes, which is typical of the pedagogical perspective.

Santoianni (2019) suggests some future perspectives at national and international level on the topics *Learning Brain* and *Teaching Brain*, with various declinations and nuances, but perhaps also the need to continue this strained but promising dialogue between neuroscience, mind, brain, education, and cognition. It invites us to consider processes of adaptability and educability, while also taking into account the explicit and implicit levels of learning, which can also be further explored in relation to teaching. In this sense, the theme of multimodality learning, i.e., the idea that learners use multi-sensory modalities, could open up interesting scenarios for exploration and study, considering a multitasking, processual, dynamic, sensory hypothesis of the teacher's brain as well.

Increased interdisciplinary collaboration between neuroscience and education can help to identify and address misunderstandings as they arise and can help to develop concepts and messages that are both scientifically sound and educationally meaningful (Howard-Jones, 2014); in some ways the hoped-for multi-level interdisciplinarity is not yet always practised.

Albeit with different methods and perspectives, the focus on the teaching brain, the *Teaching Brain* perspective, implies the possibility that knowledge derived from these studies can help teachers in their work in the classroom with students, but also, perhaps, that we are faced with dynamic processes of the brain on teaching, with a continuous modifiability. This is a still little-explored research space, it can foster new instances and questions for reflection on educational research, teaching, the brain and the interaction between teacher and pupil, not forgetting precautionary attitudes.

Neuroscientific evidence will not be sufficient because, as we know from the scientific literature, teaching-learning relationships are complex, contextual, and unique in nature, fuelled by multiple factors related to the teacher and each student, but can be an alternative and complementary route to understanding and improving instructional acts.

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