Neuroscience in education: Not a recipe book

Le neuroscienze a scuola: non un libro di ricette

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ABSTRACT The *neuro* prefix is very fashionable, and neuroeducation is just one of the myriad offsprings. Neuroscience offers an invaluable contribution to assess, diagnose, and perhaps manage pathologies, including disorders of learning in children and adolescents. However, neuroscience as such has so far proved to have little to offer to education in school. If misunderstood, neuroscience can open the gate to a number of questionable practices in the classroom. Even considering the discipline which has most to offer, cognitive psychology, the transition from lab results to school activities is challenging and should accord with didactic aims and educational contexts. Teachers and educators should resist the allure of applying neuroscientific findings and theories as if they were recipes to be carried out. In this viewpoint we will argue against the direct use of neuroscientific research findings to inform classroom education.

KEYWORDS Neuroscience; Cognitive Psychology; Education; Learning; Neuromyths.

SOMMARIO Il prefisso “neuro” è molto di moda e la neuroeducazione è solo una delle tante nuove discipline che lo utilizzano. Le neuroscienze offrono un contributo inestimabile per valutare, diagnosticare e forse gestire i comportamenti patologici, compresi i disturbi dell’apprendimento nei bambini e negli adolescenti, ma finora hanno dimostrato di avere poco da offrire all’istruzione in ambito scolastico e nella vita quotidiana. Se non correttamente conosciute o comprese, le neuroscienze possono portare a una serie di discutibili pratiche didattiche. Anche considerando la disciplina che ha più da offrire, la psicologia cognitiva, il passaggio dai risultati di laboratorio alle attività scolastiche è problematico e deve sempre essere in sintonia con gli obiettivi didattici e i contesti educativi. Insegnanti ed educatori dovrebbero resistere alla tentazione di applicare i contributi teorici e sperimentali delle neuroscienze come se fossero ricette da eseguire.

PAROLE CHIAVE Neuroscienze; Psicologia Cognitiva; Didattica; Apprendimento; Neuromiti.

1. A ONE-WAY BRIDGE

Neuroscience is very alluring for education also because the ‘neuro’ prefix is very fashionable (Legrenzi & Umiltà, 2011); neuroeducation (Donoghue & Horvath, 2022) is just one of the myriad offspring. Skimming through the scientific literature on the relationship between neuroscience and education, it becomes immediately obvious that the general consensus is that there is a gap, which needs to be bridged (Ansari & Coch, 2006; Beauchamp C. & Beauchamp M. H., 2013; Baker, Salinas, & Eslinger e, 2012; Bruer, 1997; Dougherty & Robey, 2018; Goswami, 2006; Leysen, 2021; Sigman, Peña, Goldin, & Ribeiro, 2014; Willis, 2008). However, often that gap is not filled by a two-way communication between neuroscientists and teachers, rather it constitutes a form of patronising of the former on the latter. Moreover, if anything, the scientific domain that could offer some insight to education is Cognitive Psychology, not Neuroscience (Cubelli, 2009; Anderson & Della Sala, 2012). The detailed knowledge of the neuroanatomy of the hippocampus, which is very relevant to understand how learning happens in the brain, does not inform learning in the classroom and does not better teaching methods. We posit that there should be no hierarchy between basic and applied sciences. Educational sciences and neurosciences constitute independent fields of knowledge: cognitive scientists should provide theoretical frameworks within which teachers conceive and plan educational methods and practices; teachers should contribute observations and empirical data that cognitive scientists may use to derive, test or develop theories on cognition.

2. RELEVANCE OF THE NEUROSCIENCES IN INFORMING TEACHING

Too often neuroscience is used inappropriately to promote spurious techniques in education (Howard-Jones, 2014; Hughes, Hughes, Sullivan, & Gilmore, 2020; Ritchie, Chudler, & Della Sala, 2012; Torrijos-Muelas, González-Víllora, & Bodoque-Osma, 2021), without being framed within any theory and without the necessary scientific supporting evidence. These include the ubiquitous yet unfounded belief that material presented according to alleged learning styles of individual students would facilitate learning (Pashler, McDaniel, Rohrer, & Bjork, 2008; Rogowsky, Calhoun, & Tallal, 2020) or the ungrounded view, based on a simplistic functional distinction of the cerebral hemispheres (Corballis, 1999; 2007), that stimulating the right hemisphere would enhance the students' creativity (Corballis, 2012).

Even when the science is sound, how does knowing that a given memory process activates a given area in the brain would assist a teacher in improving their pupils' learning? Would it make any difference to the classroom practices if learning activated the big toe rather than the hippocampus, as John Morton used to say? A clever way of illustrating this point was proposed by Dorothy Bishop in 2014 in her blog, discussing reading techniques[1]. She invited us to consider the following four scenarios after implementing a given training in the classroom:

1) neuroimaging shows changes demonstrating an effect and behaviour also shows effects (both demonstrate a positive outcome of the procedure used);
2) neuroimaging shows changes but behaviour shows no effect (neuroscience indicates positive outcome but behaviour does not);
3) neuroimaging shows no effect but behaviour does (behaviour demonstrates positive outcome, yet neuroscience does not);
4) neuroimaging shows no changes and behaviour shows no effects (both neuroscience and behaviour demonstrate no effect of the procedure).

Conditions 1 and 4 lead to easy decisions as the two sets of data agree. In the case of condition 2 or 3, which would be the advisable course of action? It seems evident that classroom practice should embrace those techniques that prove to have a positive effect on pupils' learning. Obviously, these four possible outcomes are rhetorical points for the sake of the argument, as behavioural effects are always associated with neuronal

[1] http://deevybee.blogspot.com/2014/01/what-is-educational-neuroscience.html

changes. Consequently, neuroscience is relevant only when its findings can be linked to those derived from behavioural observations (Coltheart & McArthur, 2012). What matters to teachers is the effectiveness of their approach and techniques, quite independently of how the brain works as revealed by the neural activities elicited in laboratory tasks. Donoghue and Hattie (reported in Donoghue, 2020) carried out a review of extant literature of the 548 papers they could glean that had the term "*Neuroeducation*" or "*Educational neuroscience*" in the title, abstract or keywords. Their results indicate that "*there was no empirical study that validly translated neuroscience into education. There was no evidence of a single classroom intervention that was prescribed based on neuroscience research*." (Donoghue, 2020, p. 96).

3. EDUCATIONAL ACTIVITIES SHOULD NOT BE INSPIRED BY PATHOLOGICAL EVIDENCE

One of the most frequent arguments put forward in support of the benefit of neuroscience in informing educational programmes comes from the perspective that the extraordinary progresses in neuroscientific research have improved the performance of people with varied learning difficulties. The assumption on which this argument is based is that interesting discoveries about learning deficits would provide the basis for bettering education in general (e.g., Goswami, 2011). However, the techniques that facilitate children with specific learning disorders and improve their performances do not inform the methods to teach all pupils, neither should they guide the selection of the stimuli or the scheduling of the subsequent steps to take. The gradient of difficulty of the stimuli and the trajectory of improvement observed in atypical conditions or in pathological contexts do not necessarily correspond to those in typical learning. For example, children with learning difficulties may find it easier to learn to write in capital letters rather than in cursive. This does not imply that all pupils should learn to write using block letters before being introduced to cursive; indeed, cognitive models (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler., 2001), in agreement with a consolidated pedagogic tradition (e.g., Chaney, 1993), maintain that no hierarchy should exist between the two styles.

Learning to read implies mastering an "*alphabetic code*" (Dehaene, 2011), recognising in a written text the presence of orthographic units representing the language sounds. The letters composing the alphabet are orthographic units, which are independent from the format (capital or lower case), the style (block letters or cursive) and even the sensory modality (visual, auditory or tactile). Learning to read requires learning to recognise each individual letter independently from its physical characteristics and acquire the knowledge that symbols apparently different from one another can express the same letter. Learning to read means acquiring the distinction between allographs, i.e. the graphic variants of letters (for instance, a, A, *a*), and abstract units, i.e. the form-invariant orthographic symbols (for instance, <A>). Based on this distinction, abstract orthographic representations are assumed to be case-invariant and, as such, insensitive to the distinction between uppercase (or capital) and lowercase letters (e.g. Dehaene, Cohen, Sigman, & Vinckier, 2005). Each letter has a name and can take different graphic shapes or non-visual configurations (like in the Braille alphabet or in the Morse code). Learning to read entails learning to derive from each physical stimulus the corresponding orthographic representation, which in turn should be recognized as a lexical unit and/or translated into a phonological sequence. Reading block letters is easier due to the space separating each letter. However, acquiring only the skill to identify specific graphic formats will result in the same drawbacks characterising the so called "*global method*" or "*whole word reading*" to learning to read (Dehaene, 2007) since it will induce the learner to undertake lexical and sub-lexical processes on the graphic forms rather than processing the orthographic information. When pupils learn to read holistically, they will be better than pupils learning analytically in reading words that they have seen before written in the exact same style. However, when presented with new words to read, or with the same words written in different styles, their performance is far poorer than that of analytic learners (e.g., Yoncheva, Blau, Maurer, & McCandliss, 2010). The behaviour advantage of orthography-based reading over whole word reading has long been corroborated by neuroscience findings (e.g., Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003).

4. THE IMPACT OF NEUROPSYCHOLOGY

The most relevant contribution of Neuropsychology to our understanding of memory structure and processes has been the introduction of the distinction between semantic and episodic memory based on both studies of patients with amnesia (see Corkin, 2013) and experiments with neurologically intact participants (Tulving, 1972; see a recent review in Pishdadian and Rosenbaum, 2022). To remember and to know are two distinct accomplishments. It is possible to remember without knowing (remembering a journey to a city, yet knowing nothing about that city). On the other hand, it is possible to know without remembering (knowing about a city without ever having been in that city).

Many teachers, assuming that declarative memory is a unitary system, contrast the study in the classroom, in the library, or at home, with the practical experience of everyday life. The first is considered repetitive and boring and therefore more demanding than useful, while the second is indicated as a privileged source of applied knowledge. Yet, they are not alternative: learning requires both personal experience and abstract knowledge, both novelty and repetition. Learning always occurs within a specific episode having a spatial-temporal context (episodic memory), but learnt information should be extrapolated from the individual episode to build or integrate abstract schemas of knowledge (semantic memory). Knowing that Paris is the capital of France ought to be associated with relevant historical, geographical, or other cultural information, yet such knowledge is no longer yoked to the event that led to its learning, such as the teacher who firstly mentioned it to us.

The distinction between episodic and semantic memory does not suggest a particular way of teaching. However, it obliges teachers to consider that these two types of memory are intertwined and necessary and that it is not appropriate to privilege one while ignoring the other. Remembering personal experiences does not equate to learning. Experiences accrued in school or in a trip may instigate emotions, curiosity and interests but do not provide full and competent learning. They may guide learning, but they do not exhaust it by substituting direct studying on books and other devices. At the same time, studying on books is not effective without doing, investigating, and discussing with others in classrooms and labs. To acquire new knowledge both episodic memory (experiencing original and personal events) and semantic memory (acquiring facts and notions) are needed.

5. TEACHING CANNOT DIRECTLY DERIVE BY APPLYING THEORIES

Theories in science are for understanding the reality, not to be applied as they were cooking recipes. Theories are not prescriptive; they suggest guidelines, show reasonable options, and signal risks to be avoided, they should not be translated into mandatory initiatives. In cognitive psychology, theories describe how the mind works in everyday life, they do not impose how to teach and learn.

The Level of Processing theory (Craik & Lockhart, 1972; see Cermak & Craik, 2014) stipulates that deep processing (e.g. semantic) results in better recollection than shallower processing (e.g. phonological). However, from this finding it cannot be inferred that rote learning should be abolished or that sheer notions are irrelevant. Proper names, dates, orthography of irregular words do not have any depth, and could be retained solely by rote learning. Elaborative encoding is crucial for comprehending and remembering (e.g., Bradshaw & Anderson, 1982): grasping meanings and connections, integrate different types of knowledge, disregard the details to derive inherent meaning, all these operations are needed to learn. Yet, surface is also important. Appreciate the content of poetry and novels, grasping their gist or studying a synopsis are not sufficient for a full-blown learning. Formal information, like wording or rhythm are essential and must be learned by heart. The same applies to scientific subjects where retaining the procedural details of the experiments is even more important than comprehending the conclusions derived by the researchers. In short, memorizing without understanding is a route to become notionists, but understanding without retaining ultimately results in ignorance[2].

The Encoding Specificity principle (Tulving & Thomson, 1973) asserts a strict connection between encoding and retrieval stages: how the information is processed determines how it will be stored and how it is stored determines which cues will be effective in the retrieval phase. It follows that memories emerge more effectively when the conditions that characterize the study phase are re-proposed in the test phase. Memory is affected by environmental context (e.g. Godden & Baddeley, 1975) and the reinstatement of a previously experienced background cues memories for events which occurred associated with that background (Smith, 1979). However, this does not imply that students should always be tested in the room where lectures are given. Evidence indicates that students do not score lower when examined in a different room (see Smith, 1988, for a review). Since attending lectures is not studying, students study outside their regular classroom; therefore, the environmental context of any exam room is inevitably different from that of the most frequently used learning place.

The principle of Transfer Appropriate Processing (Morris, Bransford, & Franks, 1977) assumes that the best way to elaborate the material to be remembered depends on the retrieval conditions in the testing phase. That is, to obtain better performances the processing requirements of the test should match the processing conditions at encoding. In educational setting, this theory does not mean that students should know in advance the format of the exam. Knowing the test modality can influence the modalities of studying, suggest strategies for organising the material, but it does not ensure a greater learning. For instance, multiple choice questionnaires would entice students to focus on details to be able to recognize them later; open questions instead invite getting the gist to build a subsequent coherent narrative. It is worth noting that studying is not geared just at passing exams but aims at gaining durable knowledge; students should demonstrate that they are competent regardless of how their competence is tested. To test the acquisition of factual knowledge, the final exams should include different types of questions. The principle of Transfer Appropriate Processing can account for incidental learning, but it is not appropriate to improve intentional learning at school.

Similarly, ill-advised enactments of sound cognitive findings concern the duration of the lectures or their timing. The findings on the limits of sustained attention (e.g., Betts, McKay, Maruff, & Anderson, 2006) do not justify the proposal of shorter lectures or minimal working load, nor do they propound the adoption of play or amusement as the best educational practice to prevent boredom or abide with the students' attitude. In short, the transition from lab results to school activities is challenging; theories from cognitive psychology can be applied, yet such applications must be modulated according to the didactic aims and the educational contexts.

6. FROM PRACTICE TO THEORY

Dunlosky, Rawson, Marsh, Nathan, and Willingham (2013) reviewed the ten techniques most frequently

[2] "*Open thy mind to that which I reveal, and fix it there within; for 'tis not knowledge, The having heard without retaining it*" (Dante Alighieri, Divine Comedy – Paradiso, Canto V, pp. 40-42, translated by Henry Wadsworth Longfellow,1867). "*Apri la mente a quel ch'io ti paleso, e fermalvi entro; ché non fa scïenza, sanza lo ritenere, avere inteso" (Original).*

used at school. The techniques which "*received high utility assessments because they benefit learners of different ages and abilities*" (p. 5) are Practice Testing (e.g. Roediger & Karpicke, 2006; Rickard & Pan, 2018) and Distributed Practice (e.g. Baddeley & Longman, 1978; Bahrick H. P., Bahrick L. E., Bahrick A. S., & Bahrick P. E, 1993). Both have a long tradition in educational learning (e.g. Gates, 1917).

Practice testing (aka Testing Effect – Roediger, Agarwal, McDaniel, & McDermott, 2011) shows that repeatedly reconstructing knowledge, by retrieving it during testing, enhances learning. For instance, Roediger and Karpicke (2006) reported that the participants in the testing condition outperformed those who reread the material on the delayed tests. This finding has been replicated several times including applications within classroom and university settings, using various types of materials, including problem-solving and procedural learning (Agarwal, Karpicke, Kang, Roediger, & McDermott, 2008; Hostetter, Penix, Norman, Batsell, & Carr, 2019; McDaniel, Anderson, Derbish, & Morrisette, 2007).

Distributed practice (aka Spacing Effect – Carpenter, 2020) is a technique whereby, being equal the total time devoted to the learning, the student spaces out their training in shorter sessions separated by intervals rather than cramming it all in longer sessions, which give the illusion of faster learning. One of the first experimental demonstration of the efficacy of spacing learning is offered by Baddeley and Longman (1978). They aimed at teaching postmen to use a new typing system. They showed that the postmen who were trained in shorter sessions spread out over several days, learned to type better and faster than those exposed to longer training closer in time to one another (massed learning).

For both techniques, the time gap between one training session and the next is relevant; progressively longer intervals result in greater learning (e.g., Karpicke and Bauernschmidt, 2011). Faced with the effectiveness of these techniques, experimental psychologists are engaged in experimental investigation to understand the mechanisms underlying these beneficial effects and to describe the cognitive mechanisms involved (e.g. Rowland, 2014). In these cases, theoretical explanation follows, rather than precedes, educational activities.

7. SLAVES OF NOVELTIES

In an interview to The New York Dramatic Mirror (9/7/1913), Thomas A. Edison was asked, "*What is your estimation of the future educational value of pictures?*". He replied "*Books will soon be obsolete in the public schools. Scholars will be instructed through the eye. It is possible to teach every branch of human knowledge with the motion picture. Our school system will be completely changed inside of ten years. (…) It proves conclusively the worth of motion pictures in chemistry, physics and other branches of study, making the scientific truths, difficult to understand from textbooks, plain and clear to children*" (p. 24).

Events proved him wrong. The great inventor's prediction resonates with those so often vented in recent years, following the emergence of digital instruments and informatics tools proposed as teaching aids (Logie & Della Sala, 2010; Rossignoli-Palomeque, Perez-Hernandez, & González-Marqués, 2018). Innovative technology can modify and improve education, but aims and results in education do not depend on technology only. Educators should resist the alluring seduction of scientific or technological novelties and fend off the temptation to demand innovation at all costs, as if continuous changing per se were a desirable scope.

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