4.6. Neuromythologies

4.6.1. *Separating science from speculation*

With the advent of functional imaging technology, cognitive neuroscience is beginning to produce important research on the neural foundations of cognitive performance. Current research results have sparked a tremendous amount of commentary and speculation among scientists, researchers, education specialists, and policy-makers. Since such research proves to have merit, many want to know how educational practice can be improved or enriched by the application of these research findings.[58] As a result of both pressure to improve overall school performance and excitement and interest about education that could be brain-based, many myths and misconceptions have arisen around the mind and brain outside of the scientific community. Teachers and educational specialists are eager to put into practice what they have read in the popular press,[59] and policy-

58. Not only educational practices, but also everyday parenthood may benefit from research findings. In fact, parents are an important "market" for neuromythologies.
59. "(...) this brain information is on the television, in the newspapers, in the magazines: what does it mean for the classroom teacher?" (Mark Fletcher, during the Granada forum). "[The teachers] hear a lot about their subjects, about mathematics or biology, or whatsoever, but they really have a big lack in neuroscientific and psychological learning theories. I think we should look into this direction and ask what teachers could learn from cognitive neuroscience." (Dr. Heinz Schirp during the Granada forum.)
Teachers, of course, are not neuroscientists, but it is both understandable and desirable that they look to the work of neuroscientists to help them improve teaching. Given that those who promulgate brain-based education to teachers fail to also convey the relative paucity of research to support their claims, teachers might be tempted to too readily adopt so-called "brain-based" teaching strategies that are in fact not based on any evidence at all. The scientific community should be sensitive to these issues. A challenge, therefore, is to strengthen pedagogical knowledge and strategies by inviting teachers to *a*) share their knowledge among themselves and *b*) share this knowledge with the neuroscientific community. Thus, the neuroscience community will be able to ground some of its research questions within the authentic experiences of good teachers. Hence, it is necessary to educate the public about both the gains due to cognitive neuroscience, but also the need to focus on "simple" questions about elementary processes first. There is of course a lot of work to do in order to integrate insights about elementary processes into the complex context faced by educators. Furthermore, educators can play a key role in helping identify such questions, that might be tractable for neuroscientists (see the Granada report on the OECD website, *op. cit.*).

makers want to enact effective educational policy by using research-based information. Even business is eager to commercialise on what is perceived of financial interest in brain-based learning tools. Due to the expectations of the applicability of brain research to educational practice, myths have rapidly developed and range from the benefit of synaptogenesis, to hemisphere dominance, to critical periods of learning and enrichment – to name the most popular ones. When misconceptions such as these are both argued for and criticised in journals and the popular press, educators and policy-makers alike are left in a quandary discerning fact from fiction. Although some myths do have some truth to them, careful reading of the original research from where they came from demonstrates that this research has often either been misinterpreted (simplified) or based exclusively on animal studies with limited implications for human beings.[60]

In the past, most scientists have claimed that at birth, the human brain has all the neurons it will ever have. However, with the advent of new technologies, this fact is being challenged. Some mechanisms, such as those that control our basic survival instincts are in place at birth, but most of the new-borns mental circuitry results from experiences – how and when these connections are formed is a subject of debate. Some scientists argued that these circuits are completed by age 3, others believed that they continue until adolescence; more recently, a consensus seems to emerge, implying that synaptic connections are formed throughout the life cycle. This emerging and recent consensus can have profound implications as to the way the education system is organised.

The goal of this section is to explain the origin of some of the more prevalent myths that the public has, to highlight why they are detrimental and/or non-effective for educational practice and to discuss how best to interpret scientific data.

The decade 1990-2000 was declared the "Decade of the Brain" in the United States. At the same time, world-wide research on the cognitive and emotional functioning of the brain has been stimulated.[61] Although much of this research has been of very high quality, some of its findings have been over-interpreted in terms of their implications for learning. Such examples are presented below.

60. While animal studies have proved essential and necessary in understanding some aspects of human development, caution must be exercised when applying results of experimental data to human learning and cognition. More generally, history shows that establishing parallels between animal and human behaviour without exercising extreme caution can prove misguided, if not dangerous.
61. This is just one example where political vision has encouraged scientific research and, beyond, started to influence educational change through appropriate funding.

Neuroscientific results must be taken as preliminary in nature for several reasons:

- Their statistical results might not be of the highest relevance (subtraction method and averaging[62]).
- Results on the same subject can differ due to methodological and theoretical considerations.
- The laboratory setting might not be the appropriate place to test a skill as it is an unnatural and contrived setting.
- A single study cannot justify a certain classroom strategy.
- In the popular press, in order to appeal to the greatest number of people, often the reporting of brain research is over-simplified; this is the origin of almost all misconceptions and misunderstandings about science.

Some current claims about the neuroscientific basis for learning must be approached with a healthy dose of skepticisim. Current and emerging technologies produce both interesting and promising results, but these will prove even more relevant and useful for education if previous misconceptions and misbeliefs about science are eradicated.

The genesis of a neuromyth usually starts with a misunderstanding, a misreading and in some cases a deliberate warping of the scientifically established facts to make a relevant case for education or for other purposes. There are three popular myths discussed in this chapter: hemisphere dominance or specialisation, synaptic development and learning, "critical" periods and enrichment (including the myth of birth to three).

62. These methods are considered somewhat weak, because comparing two different results that might share some elements in common will not clarify the differences between the two results. In neuroimaging data, for example, condition A is one task and condition B is another, different, task. In order to find the differences between them to ascertain which condition activates a particular brain area, the subtraction method is often used. This consists of looking at all the activation points on one image due to condition A and then looking at all the activation points on another image due to condition B. If the two conditions are really different, one can reason that subtracting one image from another will show only those areas in the brain pertinent to a particular condition. The problem with this method is that from one condition to another, the brain does not necessarily stop its activation from the previous condition just because the condition has ended (sometimes there's a residue of activation) and sometimes both conditions will activate the same brain areas. So defining with certainty, which brain areas are activated by a particular condition is not always accurate. Using the same example of condition A and B, the averaging method involves taking data from different subjects, for example, from the same condition and averaging together the results. The problem with this method is that even if the individual results are greatly varying (which they often are), the effects of what could be significantly different are lessened, thereby reducing potentially problematic results and generating inaccurate conclusions.

4.6.2. Hemisphere dominance or specialisation

An example of a misconception about brain science and learning concerns "right brain *versus* left brain learning". The claims about brain hemisphere specialisation and its relationship to learning point out a central shortcoming in the brain-based learning movement. It is generally asserted by non-specialists that the left hemisphere is the logical one and codes for verbal information, while the right hemisphere is the creative one and codes for visual information. Often, these ideas become polarised over time, and attributes of the brain are thought to come from either one hemisphere or the other. These attributes are then substituted for character traits making people claim, for example, that artists are "right brained" while mathematicians are "left brained".

Although Dr. Dehaene has completed an analysis[63] which demonstrated the left hemisphere's responsibility in the processing of number words (*e.g.*, "one", "two"), he also showed that both right and left hemispheres were active in the identification of Arabic numerals (*e.g.*, "1", "2"). Similarly other recent data show that when the processes of reading are analysed into smaller components, subsystems in both brain hemispheres are activated (*e.g.*, decoding written words or recognising speech sounds for higher-level processes such as reading text). Indeed, even a quintessential "right-hemisphere ability", encoding spatial relations, turns out to be accomplished by both hemispheres – but in different ways. The left hemisphere is better at encoding "categorical" spatial relations (such as above/below, or left/right) whereas the right hemisphere is better at encoding metric spatial relations (*i.e.*, continuous distances). Moreover, neuroimaging has shown that even in both of these cases areas of the two hemispheres are activated, and these areas work together. The brain is a highly integrated system; one part rarely works in isolation.

There are certain tasks, such as face recognition and speech production, which are dominant to one particular hemisphere, but most tasks require both hemispheres to work in parallel. This is an example of how certain and rather limited research findings turn into well-known neuromyths.

Asking a few questions prior to accepting published results as appropriate for education practice is necessary. Some general questions to reflect upon include:

- Is this an isolated case or are there others to support the claims being made?
- Are the studies describing events or are they testing hypotheses?
- Is the learning task used appropriate for the population tested? In other words, would this be an appropriate task for teaching school-aged children?

63. Using word masking and unconscious priming.

4.6.3. *Synaptic development, "enriched" environments and "critical" periods*

Neurons, or brain cells, are the foundation of the human brain. These cells communicate with one another via synapses, or junctions, where nerve impulses travel from cell to cell and support skill development, learning capacity, and growth in intelligence. At birth, the number of synapses is low compared with adult levels. After two months and peaking at ten months, the synaptic density in the brain tissue increases exponentially and exceeds adult levels. There is then a steady decline to (and stabilisation at) adult levels around age 10.

The process by which synapses are being created in great numbers during normal periods of growth is called synaptogenesis. It varies across the life-span with differential growth periods for different brain areas, contingent upon experience. The process by which synapses decline is referred to as "pruning" and is known to be a normal and necessary process of growth and development. In general, over the life-span, synaptic densities follow a skewed Gaussian curve with a sharp increase seen in infancy, a levelling off during adulthood and a slow decline in very old age.

In laboratory experiments with rodents, presented in New York by Dr. William Greenough, synaptic density has been shown to increase by the addition of a complex environment. A complex environment was defined in this case as a cage with other rodents, and various objects to explore. When these rats were subsequently tested on a maze learning test, it was demonstrated that those rodents as compared with a control group living in "poor or isolated" environments, performed better and faster in the maze learning task.[64] The conclusion was made that rats in "enriched" environments had increased synaptic density and thus were better able to perform the learning task.

This is the beginning of a neuromyth. Even if synaptogenesis and synaptic pruning are likely to have important learning implications for rodents, it is not proved that the same holds true for human beings. This rigorous, scientifically established experimental data on rodents has been combined by non-specialists with basic human development to assert that educational intervention, to be most effective, should be timed with synaptogenesis. The neuromyth logic is that the more synapses available, the higher the potential nerve activity and communication, thus making better learning possible. An associated belief is that early educational intervention using "enriched environments" can save synapses from pruning, or can create new synapses, thereby leading to greater intelligence or greater learning capacity. Feeding this is the additional problem of quoting the facts of a pertinent study and then assigning meaning that goes well beyond the evidence presented in the original research paper.

64. Diamond, M. *et al.* (1987), "Rat cortical morphology following crowded-enriched living conditions", *Experimental Neurology*, Vol. 96, No. 2, pp. 241-247.

Apart from the descriptive data on synaptic activity and therefore density, described above, there is not yet much neuroscientific evidence in humans about the predictive relationship between synaptic densities early in life and improved learning capacity. As Dr. John Bruer has repeatedly asserted,[65] studies on this cannot yet form the foundation for principles about how to improve formal education. However, this does not mean that brain plasticity in general, and synaptogenesis in particular, are irrelevant for learning, but further research is needed.

As could be predicted, any claim based on improper deductions and generalisations from an often misunderstood conception about synaptogenesis/synaptic pruning has its weaknesses. First, it is still difficult to obtain direct concurrent evidence relating counts of synaptic densities to learning. Up until recently, these data have been collected from humans or animals posthumously. Second, there is not yet much neuroscientific evidence in humans about the predictive relationship between synaptic densities early in life and densities later in life. Third, there is no direct neuroscientific evidence in either animals or humans linking adult synaptic densities to greater capacity to learn.[66] The point of this critique is not to condemn early educational interventions, but rather to challenge the claim that the value of early educational intervention is based on a neuroscientific consensus or brain imperative.

Considering the popular myth of "synaptic development and learning", it is wise to ask some questions: Is the study backed up by scientifically valid research? Has the study been replicated in order to arrive at consensus? Did the study or studies actually involve learning outcomes or are the implications for learning claims speculative? In general, did the study or studies rigorously test clear hypotheses or were they largely descriptive in character? How plausible is the chain of causal reasoning from the neuroscientific data to implications for learning? Of what population is the sample representative and to what population do the claims apply?

If in rodents it has been concluded that a complex environment causes increased synaptic density, and rats with more synapses[67] are thought to be smarter than their counterparts who have lived in impoverished environments

65. Bruer, J.T. (1998), "Brain science, brain fiction", *Educational Leadership*, Vol. 56, No. 3, pp. 14-18; Bruer, J.T. (1999), "Education and the brain: A bridge too far", *Educational Researcher*, Vol. 26, No. 8, pp. 4-16; Bruer, J.T. (1999), "In search of brain-based education", *Phi Delta Kappan*, Vol. 80, No. 9, pp. 648-657.
66. Bruer, J.T. (1999), "In search of brain-based education", *op. cit.*
67. Rats raised in the complex (more natural) environment had 20 to 25% more synapses per neuron (what was measured was the ratio of the density of synapses to density of neurons) in their upper visual cortex than rats raised in the deprived environment. The increase in the number of synapses per neuron was accompanied by a change in the number of blood vessels (responsible for transferring nutrients from the blood to the neurons) and in the number of other cells called astrocytes (which have a role in the metabolic support of neurons and in the growth of new synapses between them). In other words, both neural and non-neural tissue was embellished by experience.

(with presumably fewer synapses), then by analogy, the belief has arisen that providing stimulating environments for students will increase their brain connectivity and thus produce better students. Recommendations have been suggested that teachers (and parents) should provide a colourful, interesting and sensory meaningful environment to ensure a bright child.[68]

For over thirty years, neuroscientists have been collecting data about sensitive periods in biological development. As noted earlier, a sensitive period[69] is defined as a time frame in which a particular biological event is likely to occur

68. Arguing from the data on rats about the need for "enriched environments" for children is unjustified (*e.g.*, listening to Mozart, looking at coloured mobiles), particularly considering that parallel neuroscientific studies of the affect of complex or isolated environments on the development of human brains have not been conducted. On the other hand, the rat studies suggest that there is a critical threshold of environmental stimulation below which brain development may suffer. Recent studies of Romanian orphans demonstrate the ill effects of severely restricted environments, but even in these cases, rehabilitation is possible [see O'Connor, T.G., Bredenkamp, D. and Rutter, M. (1999), "Attachment disturbances and disorders in children exposed to early severe deprivation", *Infant Mental Health Journal*, Vol. 20, No. 10, pp. 10-29].
    Other problems with carelessly using this research for educational purposes lie in the following:
    - In the wild, rats naturally live in stimulating environments (drainage pipes, waterfronts, etc.) and so presumably have exactly the number of synapses needed to survive. It doesn't make sense to put them in an impoverished environment because this is an artificial setting, which is unrealistic. So if you put rats in an artificially impoverished environment, their brains will have exactly the density of synapses appropriate for that environment. In other words, they will be just as "smart" as they need to be for living in a laboratory cage. If the same line of reasoning applies to human beings (which is likely, but still has to be demonstrated), given that most humans are raised in normally stimulating environments, their brains are uniquely adjusted for their particular environments.
    - There are too many factors to take into account when defining what an "enriched" environment should look like for the majority of students.
    - The density of synapses has not been shown experimentally to affect mastery of educational skills.
    - Most children naturally grow up in environments that are stimulating. Research has shown that even children growing up in what could be traditionally defined as an impoverished environment (such as a ghetto), may continue, over time, to excel in school and go on to receive degrees in higher education.
69. Sometimes referred to as "critical period"; both terms are often used interchangeably. However, there are subtle differences. "Critical period" implies that if the time frame for a biological milestone is missed, the opportunity is lost. "Sensitive period", on the other hand, implies that the time frame for a particular biological marker is important, but not necessary in the achievement of a particular skill. Mastery can occur, but with more difficulty. Since "critical periods" seem to belong to the popular misconceptions about neuroscience, throughout this document, "sensitive period" will be used to refer to this phenomenon, except when explicitly referred to the misconception.

best. Most of the research was centred on the visual system, primarily in cats and later in monkeys.[70] Past research has shown that blindness in kittens will occur if denied visual stimulation within the first 3 months of life. Misusing scientific data on synaptogenesis, another popular misconception states that from birth to 3 years of age, children are the most receptive to learning. As a consequence of this, the belief among many non-specialists is that if a child has not been exposed "fully and completely" to various stimuli, it will not "recuperate", later on in life, these capacities "lost" in early age. Being exposed to rich and diverse stimuli is what is typically considered an "enriched" environment. However, referring back to the original literature, it should be noted that the data on sensitive periods for cat vision are not simple or always consistent. There are data to suggest that some recovery in vision is possible depending on the length of the deprivation and the circumstances following the deprivation. In other words, it is the balance and relative timing of stimulation that matter, and not that increased or "enriched" stimulation during a sensitive period make for better vision.[71] This misconception uses the previous popular beliefs about synaptogenesis and so-called "critical periods" to make a claim that for full learning to occur, rich diversity and early exposure are best; in fact, early exposure may be just fine, but the claims do not (yet?) have a basis in cognitive neuroscience.

There is a distinction to be made between synaptogenesis occurring naturally early in life and synaptogenesis associated with exposure to complex environments over the life-span. For example, data does seem to suggest that grammar learning occurs best (*i.e.* faster and easier) at a younger age (before age 16, more or less), but that vocabulary learning improves throughout life. Learning processes that depend on a sensitive period, such as grammar learning, correspond to "experience-expectant" phenomena in the sense that for learning to occur easily, relevant experience is expected to happen in a given time frame (a sensitive period). Experience-expectant learning is thought to occur best during certain periods of life. Learning processes that do not depend on a sensitive period, such as lexicon learning, are said to be "experience-dependent" phenomena, in the sense that the period during which the experience of learning can occur is not constrained by age or time. This type of learning can, and does, improve over the life-span.

Sensitive periods do exist, and could over time be useful for education and learning practice, as pointed out by Dr. Hideaki Koizumi, who suggests that "a reorganisation of the education system according to the sensitive periods of the

70. Hubel, D.H., Wiesel T.N. and LeVay, S. (1977), "Plasticity of ocular dominance columns in monkey striate cortex", *Philosophical Transactions of the Royal Society of London* (B), Vol. 278, pp. 307-409.

71. Bruer, J.T. (1998), *op. cit.*, p. 16.

brain", once these are clearly identified, would be desirable. "The most important goal in education seems to be to develop a learning capability suitable for each individual according to the sensitive periods of acquiring cognitive functions. Some basic education should be employed while the brain possesses a high plasticity; in other words, the early stage of education is important. This was known a long time ago in terms of music and language education. The progress of cognitive neuroscience, however, is leading us to further findings. The human brain functions, based upon various functional areas, consist of many modules and frames.[72] Each function module or frame would have a different sensitive period due to the plasticity of neuronal networks. (...) Although education at an early age is highly important, it does not mean that a large part of a person's education must be concentrated into the childhood years. An optimal arrangement of educational items based upon the sensitive periods is likely to be much more effective. Educational items whose sensitive periods occur later in life should be dealt with later." Thus, the neuromyth that the most sensitive period for learning is in the early years of life needs to be revised in the light of recent neuroscientific research, showing that certain forms of learning improve over the life cycle. To summarise, Dr. Koizumi suggests to "reorganise the educational system within the near future by applying recent findings in developmental cognitive neuroscience".[73]

72. See Foder, J.A. (1983), *The Modularity of Mind*, MIT Press, Cambridge; and also Koizumi, H. (1997), "Mind-morphology: an approach with non-invasive higher-order brain function analysis", *Chemistry and Chemical Industry*, Vol. 50, No. 11, pp. 1649-1652.
73. Koizumi, H. (1999), "A Practical Approach to Trans-Disciplinary Studies for the 21st Century – The Centennial of the Discovery of Radium by the Curies", J. *Seizon and Life Sci.*, Vol. 9, No. B 1999.1, pp. 19-20.