Spotlight 92

UNIVERSITY of GLASGOW

Neuroscience and education

What can brain science contribute to teaching and learning?

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This Spotlight is based on a review of brain-based learning and what is currently known of its implications for learning, and was undertaken during 2004 by the SCRE Centre. It was commissioned by the Scottish Executive Education Department. It gives a brief overview of the different disciplines involved and how they inter-relate, and considers some of the facts, assumptions and 'neuromyths' which have arisen from this interdisciplinary approach.

The full report, including detailed references, is also available from the SCRE website as Research Report 121.

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BACKGROUND

Educationalists are becoming increasingly aware of the advances in understanding that neuroscience is making, and are looking for insights it can offer to improve their practice. In recent years this interest has resulted in a number of publications aimed at a general readership, including parents and teachers. As we shall see, some of what has been written has been extremely enthusiastic about the possibilities for education opened up by advances in the neurosciences. There has also, however, been an almost inevitable backlash from sceptics who claim that the enthusiasts have over-simplified neuroscientific research and over-interpreted its findings, generating a number of 'neuromyths' in the process (eg Bruer, 1997; Davis, 2000; OECD, 2002).

NEUROSCIENCE, PSYCHOLOGY, AND EDUCATION

In 1997 John Bruer published an influential statement of the sceptic's view of the relationship between neuroscience and education in which he distinguished between 'neuroscience', 'cognitive science', and 'education'. He argued that it was possible to bridge the gap between neuroscience and cognitive science, and also to bridge the gap between cognitive science and education, but that the overall gap between neuroscience and education was too wide to bridge in one span as it was 'a bridge too far' (Bruer, 1997). It is possible to make even finer distinctions than Bruer, and amongst references to 'brain science' as a general and fairly neutral term, there are also more technical terms such as 'neurobiology', 'neurophysiology', 'cognitive neuroscience', 'cognitive psychology', 'educational psychology' and variations on these. The important point to make is that there are at least three distinctive types of study involved. The boundaries between them can become fuzzy, and there is growing interest in the links between them, but a crude characterisation of them would be to say that:

- ❑ At the first level, scientists are concerned with the inner workings of the brain. This is the level of 'neuroscience' where various aspects of biology, physiology, and chemistry are concerned with the structure, organisation and development of the brain as a physical organism;
- ❑ At the second level, the brain is thought of as a 'black box', studied experimentally from outside. This is the level of 'psychology', particularly in its experimental and cognitive forms, and is interested in the behavioural impact of various types of input applied in specified contexts;
- ❑ At the third level we are dealing with the practical application of knowledge about human behaviour to promote effective

teaching and learning. This is the realm of 'education' which is as much a social endeavour as a scientific one.

Of course, neuroscience has implications for psychology, just as psychology has for education: 'cognitive neuroscience' is attempting to link the first and second levels, and it is easy to see that disciplines like social psychology or educational psychology are as close to the third level as the second, but these distinctions are a useful reminder that it is a very long journey from a discovery about the physiology or organisation of the brain to a practical application in a classroom.

As a recent OECD report emphasises, there are also practical and methodological difficulties in making such connections:

> Current research methods in cognitive neuroscience necessarily limit the types of questions that are addressed. For example, questions such as "How do individuals learn to recognise written words?" are more tractable than "How do individuals compare the themes of different stories?". This is because the first question leads to studies where the stimuli and responses can be easily controlled and contrasted with another task. As such, it becomes understandable in reference to known cognitive models. The second question involves too many factors that cannot be successfully separated during experimental testing. For this reason, the type of educational tasks favoured by society will remain more complex than the ones that might suit cognitive neuroscience.
>
> (OECD, 2002)

Byrnes and Fox (1998) note other methodological problems with the range of research methods (including invasive techniques, animal studies, and a range of imaging/ scanning techniques) which scientists have so far devised. Each method has its strengths and weaknesses, and produces results which need to be interpreted with care. In particular, the authors note the difficulties of making generalisations based on loss of cognitive function due to brain lesions in individual patients, particularly given the distributed nature of that function (see below). They also note difficulties with extrapolating from animal studies to possible implications for human learning, and with the various brain scanning and measuring techniques (such as EEG, MRI and PET scans) which, according to Posner *et al* (2001), are limited in terms of the generalisability of findings by the spatial or temporal resolution which they can achieve, by practical difficulties in conducting the scan, and by questions about the suitability of different techniques for different types of subject.

Having noted these cautions, we will now look at what we know of the brain, how we know it, and what some important neuroscientific studies have to suggest about the brain and learning.

NEURONS AND SYNAPSES

The average adult human brain weighs around one and a quarter kilograms and contains somewhere in the region of 100 billion active nerve cells, known as neurons, which are responsible for all our mental activity. The neurons form the 'grey matter' of the brain. Alongside them there are also many billions (possibly 1000 billion) 'glial cells' which form a supporting structure, but do not contribute directly to mental activity. Each neuron consists of a cell nucleus, a 'tail' known as an axon which functions as the route for the transmission of electrical messages from the neuron, and a large number of smaller branching structures, known as dendrites, which act as receptors for messages from other neurons. Messages between neurons do not seem to operate in a binary fashion – ie it is not the case that a neuron is switched 'on' or 'off' like part of a computer circuit – but rather the level of activation of neurons appears to be continuously variable. The connection between neurons – the point at which a dendrite receives a message from an axon – is known as a synapse. In this way any one neuron may be connected to many thousands of other neurons. While the total number of neurons in the human brain remains relatively constant from birth, the number of synaptic connections between neurons undergoes significant changes, and much of neuroscience has been concerned with studying these changes.

It is now believed that almost all the neurons which will eventually comprise the mature human brain are formed while in the womb and are present from birth (although it has recently been reported that some parts of the brain have been found to generate new neurons (OECD, 2002: 67)). What changes most dramatically is the growth of axons, and dendrites, and the number of synapses connecting neurons. This process is known as synaptogenesis and seems to occur in different parts of the brain at different times. Somewhat counter-intuitively, it also results in the developing brain having far more synapses than will be present in the adult brain: one part of brain development consists not of growth, but of 'pruning' of the number of synaptic connections between neurons, a process which appears to be a variety of 'fine tuning' of the brain in response to environmental stimuli, and results in the reduction of the number of synapses to adult levels. As development continues a process known as 'myelinisation' takes place. This involves an increase in the coating of the axon of each neuron which serves to improve its insulation and therefore make the established connections more efficient. The ability of the brain to change as a result of learning, or in response to environmental changes, is known as 'plasticity' and is particularly apparent in, but not confined to, infants in the early years of development.

The educational implications of what is known about synaptogenesis, pruning and plasticity are significant. In particular, the implications of continued plasticity should be reassuring for all proponents of lifelong learning – it is, put simply, never too late to learn. Brain research in the area of ageing tends to concentrate on the study of pathologies and diseases and their effects, but what it tells us about normal healthy brains is optimistic in that it suggests that old dogs can indeed learn new tricks.

The idea that there are 'critical' periods for brain development derives principally from sensory deprivation studies on animals and is therefore problematic on several counts: namely, the fact that such studies relate only to the sensory system, and the question of whether synaptogenesis follows the same pattern in humans. Furthermore, the assumption that the period of maximum synaptogenesis corresponds with the period of maximum learning – and that more synapses mean more brainpower – has simply not been demonstrated by research. Consequently, neuroscientists have now shied away from the term 'critical periods', identifying instead certain types of learning which are subject to periods when the brain seems to be primed for particular types of input. Such periods are not confined to the early years of childhood, and they are not as dramatically critical as some proponents originally believed. The idea that it is a case of 'use it or lose it' appears to be an exaggeration of the truth.

Skills and abilities which are naturally evolved in humans appear to be more prone to sensitive periods of development than culturally transmitted knowledge. The former ('experience expectant' learning) has been conditioned by our evolutionary development and occurs where the brain *expects* certain kinds of input (eg visual, tactile or auditory stimulus) to which it will adapt itself. It is a response to our environment which allows the brain to fine-tune itself, and it may be subject to 'sensitive periods' when the brain is particularly ready to respond to these stimuli, which are ever-present in the environment. 'Experience dependent' learning, by contrast does not have these constraints. It is the type of learning which will only occur if the need arises for it, and tends to be of the sort which features in culturally transmitted knowledge systems.

There are no grounds for believing, then, in the supreme importance of the first three years, nor in the efficacy of any form of infant 'hot housing'. Any normally stimulating human environment will be (in neuroscientific terms) sufficient for normal human infant development. What is important at this stage is that any sensory or motor impairment should be identified as soon as possible in order that remediation can begin. This is because the main sensitive periods in early childhood appear to concern sensory and motor development and those skills and abilities which humans are conditioned to develop by their evolution (including spoken language). The sooner remediation of any deficit begins, the greater chance there is of overcoming the deficit. There is less certainty about any later sensitive periods, although it does appear that some skills, such as learning a musical instrument, or learning a second language, will benefit from learning which takes place before the age of around 12 or 13. Some recent research may suggest that there is a possibility of another sensitive period for reasoning and problem solving abilities in the teenage years, but this is at present still speculative.

LOCALISATION OF FUNCTIONS

Byrnes and Fox (1998) outline the history of a long-standing argument between proponents of the view that specific cognitive functions are localised in particular areas of the brain (the 'localists'), and those who believed that 'all regions [of the brain] have an equal ability to perform different tasks' (the 'globalists'). The arguments in favour of the localists derived from studies of brain injuries or lesions in particular areas of the brain which result in loss of specific functions, while the globalists drew on data which showed that injuries in different parts of the brain can result in the same deficit, and animal studies which showed that large parts of rat brains could be removed without any apparent deficit.

As might be expected, the current view is more complex, and to some extent accommodates both views. It is now thought that almost any cognitive function is composed of the combined action of a number of smaller 'elementary' functions, at least some of which are localised. These elementary functions may be widely distributed across the brain, may be performed in parallel, and may involve an element of 'redundancy' so that the brain can perform complex functions even with the failure of some elementary ones. Such functions may also work by 'probabilistic action', meaning that certainty does not need to be achieved for a function to be performed.

It is also increasingly clear that the synaptic connections within the brain can change and re-form throughout life as a result of learning, or in response to injury or environmental change (Goswami, 2004), so that 'the brain retains its plasticity over the life-span' (OECD, 2002).

Perhaps the most well known fact of brain geography is that it is split into two hemispheres, the left and the right, which are connected by a mass of nerve fibres carrying messages between the two. There is a popular assumption about the implications of research on brain laterality which has somehow become established as common belief, but which is not justified by the research (a 'neuromyth': OECD, 2002). This is the idea that the two halves of the brain work in fundamentally different ways: the 'left brain' usually being characterised as the logical half of the brain, concerned with reasoning, problem-solving, and language, while the 'right brain' is the intuitive and creative side, concerned more with images than words. Popular accounts based on this notion have been around for many years, and still appear within the literature, but are unfortunately based on a gross over-simplification which is not supported by the brain research literature (Bruer, 1999; OECD, 2002). It was based largely on studies of 'split brain' patients who had the corpus callosum (which connects the two hemispheres) severed as a treatment for epilepsy. This is a highly abnormal circumstance which results in disruption of communication between the two halves of the brain. In the normal, healthy adult human brain such gross characterisations of 'laterality' do not hold.

ENRICHED ENVIRONMENTS

This neuromyth is based on an extrapolation from studies of rats brought up in either 'enriched' or 'deprived' environments: rats brought up in the 'enriched' environment were found to have greater synaptic density in their brains. Commentators have extrapolated from this that young children should be brought up in an 'enriched' environment in order to enhance their learning potential. There is no evidence in humans linking synaptic densities and improved learning; and there is no evidence relating synaptic densities in early life with those in later life. The reasoning has also been criticised on the grounds that the so-called 'enriched' environment for the rats was, in fact, much closer to a normal rat environment, so that what the study showed was the detrimental effects of an artificially 'deprived' environment. There is some human evidence to support this second conclusion.

The original rat studies also went on to show that the effects of environment (whether 'enriched' or 'deprived') were evident in rats of all ages, and not just young rats. They were providing, in fact, evidence for the continued plasticity of the brain. A final problem is that, as John Bruer has put it, ' "enriched", when applied to early education for humans, is very much in the eye of the beholder, often reflecting the beholder's cultural and class values' (Bruer, 1997), and this preference is definitely not supported by neuroscience.

MYTHS TO COME?

There is some evidence of other myths coming into circulation. In particular, ideas about the 'gendered brain' and 'implicit learning' are appearing (Goswami, 2004). The notion that there are identifiable differences between males and females in brain structure and organisation is occasionally encountered and may have some basis in fact (Blakemore & Frith, 2000), although the OECD notes that any implications for education are, at present, 'equivocal' (OECD, 2002).

'Implicit' learning is said to occur when the brain absorbs information which is not consciously being attended to (Blakemore & Frith, 2000; OECD, 2002). It is certainly an important factor to bear in mind when trying to avoid distractions from learning. However, experiments which have investigated implicit learning have tended to concentrate on perceptual learning tasks rather than cognitive tasks, and there is some doubt as to whether implicit learning is applicable to cognitive tasks (Goswami, 2004).

STRIVING FOR CONSENSUS

It seems clear that the sceptics are right to criticise some of the wilder claims that have been made for the place of neuroscience in education. Some educationalists have been keen to appropriate neuroscientific research to promote their own views, in which respect some are on firmer ground than others, and some owe at least as much to the psychological literature as to the neuroscientific literature. It is noticeable that there is less traffic in the other direction, so that 'it is rare to find an article written by a neuroscientist in the educational literature' (Bruer, 1998).

It is also fair to say, however, that the case made by the 'enthusiasts' has not been entirely dismissed. What has faded slightly is the belief that some grand scheme of 'brain based education' can be made instantly available to transform learning and teaching. In its place is a more cautious and incremental approach which acknowledges that our current state of knowledge is incomplete and may be, in some aspects, inaccurate. It is also being increasingly acknowledged that any account of how education works which makes any claim to being complete, coherent, and scientific, will need to be entirely congruent with what we know about how the brain works. Attempts are being made to link neuroscientific research, cognitive psychology, and education by a more careful and realistic drawing out of the implications of neuroscientific research, but also by using the insights of education and psychology to guide neuroscience towards new areas of research. A cautious new synthesis is beginning to emerge and something approaching a consensus can be discerned in the more recent literature.

There are grounds for some optimism: neuroscientific findings are beginning to shed some helpful light on a few particular areas of learning, including language learning, literacy, numeracy, dyslexia, and the link between emotion and learning. More information on these and other areas of research can be found in the full report from this review, available as SCRE Research Report 122 on the SCRE website.

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The OECD has recently established a 'Learning Science and Brain Research' web forum for teaching practitioners: <http://www.teach-the-brain.org>.