INNOVATIVE TEACHING FOR EFFECTIVE LEARNING

Background Document: "New Findings from Neuroscience Research: Are There Implications for Teachers' Knowledge Base?"

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This paper is being developed as part of the background research for the ITEL project. The purpose of the paper is to report on new findings from developmental cognitive neuroscience with implications for learning. The paper makes the argument that a new science of learning has emerged which combines insights from cognitive science, neuroscience, and psychology which has implications for teachers' practice. The paper sets forth a proposal for this new research to become part of a framework of teachers' pedagogical knowledge. Having defined the place of the proposed framework within the broader concept of pedagogical knowledge, the report will provide a non-exhaustive review of 1) overarching neuroscience concepts and methods and 2) specific examples of research from within neuroscience that should be integrated into frameworks of teachers' pedagogical knowledge. This review paper is part of the conceptual work currently in progress in ITEL and accompanies the ITEL "Progress Report" [EDU/CERI/CD(2013)11].

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NEW FINDINGS FROM NEUROSCIENCE RESEARCH: ARE THERE IMPLICATIONS FOR TEACHERS’ KNOWLEDGE BASE?

Introduction

Why Should Evidence from Neuroscience Inform Teachers’ Pedagogical Knowledge?

1. Neuroscience is a rapidly growing field of inquiry. Tens of thousands of individuals attend the annual meeting of the Society for Neuroscience (www.sfn.org). The field is growing at a stunning pace. Neuroscience covers investigations at multiple levels of analysis ranging from the study of how genes influence the functioning of single nerve cells through to the study of large-scale systems and networks in the brain and how these generate human behaviour.

2. Not only do neuroscientists work at multiple levels of analysis, but their work also intersects with many other disciplines, such as Philosophy, Psychology, Anthropology and Economics, to name just a few. Almost every week new breakthrough studies in neuroscience are published, increasing our understanding of how the brain works. Neuroscience is becoming a hub science for addressing key questions concerning humanity, such as how we develop, how we learn complex, cultural skills such as reading, what drives our behaviours, how do we make decisions, and how do our emotions influence our decisions. Newspapers are now filled with reports about the latest neuroscientific research and how this might impact the reader’s life. As a consequence, there is growing public interest in findings from neuroscience, raising the importance of neuroscientists becoming involved with efforts to diffuse accurate knowledge into the public consciousness and considering ethical challenges of the implications that can and are being derived from neuroscience research on the human condition (Illes et al., 2010; Morein-Zamir & Sahakian, 2010). For example, new insights into how measures of brain activation predict educational outcomes need to be carefully reported to avoid that misconceptions arise (e.g., the misconception that because measures of brain structure and function predict educational outcomes, there is nothing that educators can do about the process of learning). In other words, scientists need to provide balanced accounts that take into account the scientific literacy of the audience and guard against misconceptions and potential misapplications of the evidence. As is evident, neuroscience is a highly complex science and handling the implications of neuroscience for individuals and society at large is a complex and multi-level endeavour.

3. In the domain of human neuroscience, fuelled by the advent of non-invasive neuroimaging methods, such as functional Magnetic Resonance Imaging (fMRI) and many other methods, it has become possible to look at how the brain functions in humans and to study the neural correlates of complex human behaviours, such as problem solving and the processing of emotions. Consequently, a new, interdisciplinary field of inquiry has flourished: Cognitive Neuroscience. Cognitive Neuroscience represents the integration of cognitive psychology and neuroscience. In other words, as one of the founders of the field, Michael Gazzaniga, puts it, “Cognitive Neuroscience is the study of how the brain enables the mind” (Gazzaniga, Ivry, & Mangun, 2008). In other words, Cognitive Neuroscience is providing biological constraints on our understanding of human psychology. This field of interdisciplinary inquiry is rapidly growing and is starting to investigate questions relevant to virtually all aspects of human behaviour. Today, Departments of Psychology at universities throughout the world are becoming increasingly populated with researchers who integrate neuroscientific methods and approaches into their study of psychological processes. Indeed, many Departments of Psychology have renamed themselves to acknowledge the growing role that neuroscience plays in psychological research and are now called ‘Department of Psychological and Brain Sciences’ or ‘Department of Behavioural and Brain Sciences.’

4. As part of this field, researchers have gained unprecedented insights into human brain development through neuroimaging studies with children. Such studies have looked at age-related changes in both the structure and functions of the brain (Casey, Giedd, & Thomas, 2000). Through such studies it
has become possible to investigate how the brain changes over developmental time and how experiences influence brain structure and function. Often such efforts are referred to as studies in a subfield of Cognitive Neuroscience, known as Developmental Cognitive Neuroscience (Johnson, 2001; Munakata, Casey, & Diamond, 2004). Developmental Cognitive Neuroscientists study how the brain changes as a function of experience (brain plasticity) and how this varies over the course of learning and development. By doing so, Developmental Cognitive Neuroscientists study how children learn complex skills such as reading, writing, and arithmetic and how the acquisition of these skills is influenced by other cognitive functions such as working memory, attention, sleep, and exercise, to mention just a few. Furthermore, researchers in Developmental Cognitive Neuroscience address questions relevant to adolescent risk-taking, the role of sleep and exercise in learning, and how arts education affects the brain, to mention just a few of the topics that are investigated by researchers in this quickly growing field. In this context it is also important to note that Developmental Cognitive Neuroscience is not simply concerned with topics typically associated with the study of cognition, such as reasoning, problem-solving, and thinking, but also encompasses the study of social behaviours, the influence of emotional factors, such as motivation and reward processing, in an effort to better understand the interface between emotion and cognition and their interactive neural substrates.

5. A key neurobiological process that is investigated by Developmental Cognitive Neuroscientists is typically referred to as ‘neuronal plasticity’ – the ability of the brain to change as a function of experience. Early neurophysiological studies revealed that sensory deprivation (i.e., patching one eye of an animal to restrict the amount of visual information that is relayed to the brain) or enrichment (i.e., adding toys and/or other animals to a cage of an animal that was previously isolated) change the brains of animals, revealing that experience shapes the brain (Buonomano & Merzenich, 1998). In other words, the brain responds to experience and changes its structure as a consequence of alterations in the environment. This is what is called ‘plasticity.’ Today, we can study the effects of complex environmental and experiential differences, such as cross-cultural and socio-economic variability, on brain structure and function (Ansari, 2012; Hackman, Farah, & Meaney, 2010; Noble, Wolmetz, Ochs, Farah, & McCandliss, 2006). Mounting research suggests that the brain is more plastic than we originally thought (though, importantly, within constraints) and that our brains continue to be capable of functional and structural change (plasticity) in adulthood, which has potential implications for life-long learning, a topic of much interest in many ageing Western societies (for a recent review see May, 2011).

6. Plasticity is key to education: Without the ability of the brain to change in response to experience, education would not be possible. If our brain were static organs or had very limited ability to change in response to information, then our ability to learn would be severely compromised. In other words, the brain allows humans to be educated and, at the same time, puts constraints on the effects of education. For learning to occur the brain needs to be able to encode, retrieve, and process information and this requires physical changes within brain circuitry. This type of change in the brain architecture in response to experience is often referred to as ‘experience-dependent brain plasticity.’ Experience-dependent plasticity represents the key mechanism by which individuals learn to adapt to their unique socio-cultural niches and function successfully within them (Greenough, Black, & Wallace, 1987). Thus, in order for children to learn, experience-dependent plasticity needs to occur. Even though most may not be aware of it, teachers are tasked with finding the best way to induce experience-dependent brain plasticity in order for students to encode knowledge, make connections between different pieces of information, acquire essential skills, etc. It follows from this that teachers are the orchestrators of their students’ neuronal plasticity during classroom time. In view of this, one of the key conceptual pillars of the present paper is that if teachers possess a greater understanding of neuroscience, their practice would be significantly enriched. More specifically, we contend that accurate information transfer from neuroscience to teacher education will, in deep interaction with their experience, affect and inform their pedagogical decision-making.
7. Notwithstanding strong critics (e.g., Bruer, 1997), over the past 15 years or so the enthusiasm for a new science of learning and education that combines insights from cognitive science, neuroscience, and psychology to inform education has grown exponentially. Terms such as ‘Neuroeducation,’ ‘Educational Neuroscience,’ and ‘Mind, Brain and Education’ have been used to describe these efforts. In the present report, we use the term ‘developmental cognitive neuroscience’ in reference to this field of research.

**Scope And Methods**

8. It is clear that teachers are actively seeking to learn more about the latest research and how it might impact their practice. For example, the ‘Learning and the Brain’ conference series is attended by thousands of teachers from around the world. There are many new resources such as online courses and books (e.g., Tokuhama-Espinosa, 2011; Blakemore & Frith, 2005) that teachers can make use of if they choose to seek out such information.\(^1\)\(^,\)\(^2\) This provides an important basis for the potential success of educating educators about neuroscience in an effort to inform their practice. In fact, evidence suggests that teachers believe that knowledge about brain function will aid their pedagogy by helping them to understand the mechanisms underlying their students’ learning (Dubinsky, 2010; Pickering & Howard-Jones, 2007), and there is already some evidence to suggest that when teachers learn about neuroscience it positively impacts their practice (Dommett, Devonshire, Plateau, Westwell, & Greenfield, 2011).

9. While the field of developmental cognitive neuroscience is growing rapidly, the ways in which research within this field are translated into education are not formalized. What is currently lacking is a systematic integration of neuroscience evidence into the knowledge that teachers are expected to have to optimally carry out their profession. Anecdotal reports suggest that evidence about how children’s brains develop and learn, and the variables that affect these developmental processes, is not a focus of current pedagogical knowledge frameworks. As such, if teacher education programs do include empirical research on how children learn and development, the knowledge transmitted is based on comparatively old theoretical models (e.g., Jean Piaget, Lev Vygotsky). The aim of the present report is to propose a formalized (rather than just ad-hoc and dependent upon the initiative of educators) integration of the latest neuroscience evidence into a framework of teachers’ pedagogical knowledge.

10. The central contention of the present report is that one of the most efficacious ways of bringing research from neuroscience to bear on education is to make it part of teachers’ pedagogical knowledge both through pre-service teacher education as well as through on-going professional development. In order to present how this might be achieved and what kind of knowledge from within neuroscience would become part of teachers’ pedagogical knowledge, the present report consists of three sections. The report will begin with a non-exhaustive review of 1) overarching neuroscience concepts and methods and 2) specific examples of research from within neuroscience that should be integrated into frameworks of teachers’ pedagogical knowledge. This two-part review serves to illustrate what topics from within neuroscience should become part of teachers’ pedagogical knowledge. Critically, the description of these examples will also provide a discussion of why each example should be integrated into frameworks of teachers’ pedagogical knowledge. In the third and final section, the focus will be to consider how neuroscience evidence can become part of teachers’ pedagogical knowledge. Moreover, this part of the report will also serve to illustrate clearly which aspects of pedagogical knowledge can be influenced by the latest evidence from neuroscience, and therefore also highlight which components of pedagogical knowledge cannot be informed by neuroscience. This is important, as the aim of the present report is not to propose a framework of teachers’ pedagogical knowledge that will overturn or replace existing ones, but

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1. [http://www.learningandthebrain.com](http://www.learningandthebrain.com); [http://www.learner.org/courses/neuroscience/about/about.html](http://www.learner.org/courses/neuroscience/about/about.html)

2. The OECD is not endorsing any specific conferences or books in connection with this research.
rather add to what are already considered to be the essential components of teachers’ pedagogical knowledge.

11. It is important to emphasize at the outset that the aim is not to integrate knowledge that is prescriptive in terms of teaching practice. The proposal is that information about how children’s brains learn, develop, and change as a function of experience will help educators to become more informed practitioners and to see the children in their classrooms in the light of evidence about child development and learning. It is the integration of this knowledge with their experience that will influence their practice. The analogy with medical education is useful here. All doctors in training will take courses on molecular and cellular biology and the importance of doctors acquiring this knowledge is not questioned. Yet it is also clear that this knowledge is not going to lead to clear prescriptions in medical practice, but rather form an important aspect of multiple knowledge sources that inform the practice and decision-makers of doctors. The present report proposes that the research from within developmental cognitive neuroscience can serve a similar, important function in informing educational professionals by serving as part of the broader knowledge that educators bring to the task of teaching. Furthermore, by instilling a culture of evidence-based practice, educators will be better equipped to evaluate programs and seek out approaches that are evidence-based and have been shown to be efficacious. This will also enable educators to evaluate apparent ‘facts’ about the brain that are presented to them and thus avoid accepting information that is not evidence-based or presents misconceptions about the brain (e.g., so-called ‘neuromyths;’ Dekker, Lee, Howard-Jones, & Jolles, 2012; Goswami, 2003).

12. What follows is an outline of the topics that will be covered in the report. The report is expected for completion by March 2014.

Part 1: Overarching Methods and Concepts

13. The aim of this section is to provide an accessible and concise (yet accurate) overview of concepts and methodological approaches that, according to the proposal put forward in this report, should become part of teacher’s knowledge base. This report will argue that an understanding of these methods and concepts will turn teachers into more informed practitioners in an age where evidence from neuroscience is, for better or worse, increasingly being drawn upon to help inform many problems that humanity faces, including how best to educate our children. A clear understanding of key concepts and methods in neuroscience and their limitations, as well as a toolkit to enable critical reflection and evaluation, will help teachers, in combination with their experience of being teachers, optimize their practice. In other words, we provide an outline of the kinds of overarching concepts and understanding of research methodologies that should, in the future, form part of either pre-service teacher preparation or ongoing professional development.

Overview of Research Methodology and the Notion of Evidence-Based Practice

14. This section will provide an overview of what research is and how it is conducted. The focus will be on empirical, quantitative research, but qualitative research will also be briefly discussed. By doing so, this section will discuss the basic tenets of research such as experimental design, the importance of experimental control, the notion of independent and dependent variables, the notion of variance, and some basic notions of what statistical significance means and what its limitations are (e.g., limitations of regression to the mean).

15. This section will also discuss the concept of action research – something that teachers can engage in themselves to be able to use evidence to constrain decision-making that is specific to their context. Indeed, through action research educators can become active participants in building the knowledge base.
16. An important part of this section will be to review developmental approaches to the study of brain development and the emergence of educationally relevant brain functions. The review will therefore discuss longitudinal vs. cross sectional approaches and the importance of looking at evidence from children to draw implications for educational practice. Too often findings from adult neuroscience are being generalized to the study of children and their learning. This kind of extrapolation carried various problematic assumptions with it and this issue will be briefly discussed.

17. In addition to discussing these basic concepts briefly, this section will also introduce the notion of evidence-based practice and the importance of evaluating evidence that one is being asked to apply in the classroom. The concept of peer-review will be discussed, and within this, strategies for evaluating research through asking the right kinds of questions when looking at a new educational product or proposed pedagogical concept or notion.

**Overview of Methods Used to Study the Brain and Mind**

18. This section will review methods that are currently used to study brain function. Particular emphasis will be placed on methods that are used to study the relationship between brain and behaviour (or brain and mind). Specifically, methods to collect behavioural data (e.g., reaction times and accuracy) will be reviewed. The review of methods to non-invasively measure brain function will cover methodological approaches such as functional Magnetic Resonance Imaging (fMRI), structural neuroanatomical measures such as structural MRI and Diffusion Tensor Imaging (DTI), Electroencephalography (EEG), which allows for the measurement of event-related potentials, ERPs, as well as time-frequency analyses, Trans-cranial Magnetic Stimulation, Trans-cranial Direct Current Stimulation (TDCS) and Near Infrared Spectroscopy (NIRS).

19. Importantly, this overview will not simply describe each of these methods, but provide a discussion of the strengths and limitations of each method (temporal vs. spatial resolution, indirect vs. direct measurement of brain function, ecological validity, etc.).

**Overview of Key Concepts in Developmental Cognitive Neuroscience**

- Basic neuroanatomy: A brief review of the key vocabulary when we discuss structural neuroanatomy such as neurons, glia cells, dendrites, axons, synapses, white matter, gray matter, gyri, sulci, the major lobes of the brain.

- Pre and postnatal brain development: Review of key concepts such as synaptogenesis and synaptic pruning, changes in grey vs. white matter. They key concept of major changes and changes in connectivity.

- Brain plasticity: A more detailed review than is provided in the introduction with key examples from the literature, including a brief discussion of long-term potentiation as the low-level mechanism for plasticity. Also including a discussion of the important distinction between experience-expectant and experience-dependent brain plasticity.

- Critical vs. sensitive periods: This discussion will build on the review of brain plasticity to cover the timing of experience and brain plasticity. It will discuss the distinction between critical and sensitive periods to provide a balanced overview of this notion, which is so frequently discussed in education. Concrete examples from research will be reviewed to show that the use of sensitive periods is a more accurate reflection of what we know about the timing of experience in inducing optimal brain plasticity. In this context, evidence for life-long brain plasticity will also be discussed.
• Biological embedding: The concept that experience and the environment change the child’s biology will be discussed and the role of early stress on brain development will be used as an example to describe this powerful concept.

• A discussion of frequently reported misconceptions and neuromyths, and an explanation of where they came from and why they are myths.

Part 2: Developmental Cognitive Neuroscience Findings Relevant to Education

20. In this section, recent findings from the field of developmental cognitive neuroscience with implications for teaching and learning will be reviewed along the following themes:

• Social-emotional cognition
• Memory
• Attention and executive control

Part 3: Implications for Practice

21. The argument being made in this report is that there is a strong case for new knowledge from the field of developmental cognitive neuroscience to be incorporated into teachers’ knowledge base. How is this to be done?

22. As there is wide variation in teacher training requirements and school autonomy in different OECD countries, it is not possible to be prescriptive about how change in teachers’ knowledge base might be achieved. For example, in some countries teachers have no formal qualifications whereas an undergraduate or master’s degree in education is required in other countries.

23. The discussion in this section will focus on the following issues:

• Forms of teacher pedagogical knowledge and how neuroscience research might be integrated into this knowledge base.
• Factors making it difficult for teachers to integrate new knowledge from the neurosciences into their pedagogical knowledge base.
• Levers for bringing about change in teachers’ knowledge base.

24. The following pages are a bibliography of sources that will be reviewed in conducting this work.


Sleeter, C. (2013). Toward Teacher Education Research that Informs Policy. Key Note Presentation Australian Teacher Education Association, Brisbane, Australia, June 2013 and in press.


