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INNOVATIVE TEACHING FOR EFFECTIVE LEARNING

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

21-22 November 2013

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

1. http://www.learningandthebrain.com; 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 on-going 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.

BIBLIOGRAPHY

Adams, M. J. (1990). *Beginning to read: Thinking and learning about print*. Cambridge, MA: The MIT Press.

Adolphs, R. (2009). The social brain: neural basis of social knowledge. *Annual review of psychology*, *60*, 693.

Anderson, S. R. (2004). How many languages are there in the world?. *Washington, DC: Linguistic Society of America*.

Ansari, D. (2012). Culture and education: new frontiers in brain plasticity. Trends in Cognitive Sciences, 16, 93–95. doi:10.1016/j.tics.2011.11.016

Ansari, D. (2007). Does the parietal cortex distinguish between "10,""ten," and ten dots?. *Neuron*, *53*(2), 165-167.

Ansari, D. (2005). Time to use neuroscience findings in teacher training. Nature, 437(7055), 26. doi:437026a [pii] 10.1038/437026a

Ansari, D, & Coch, D. (2006). Bridges over troubled waters: education and cognitive neuroscience. Trends in Cognitive Sciences, 10(4), 146–151. Retrieved from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=16530462

Arbisi-Kelm, T., & Beckman, M. E. (2009). Prosodic structure and consonant development across languages. *Phonetics and Phonology*, 109-136.

Babcock, M.K. & Freyd, J.J. (1988). Perception of dynamic information in static handwritten forms. *American Journal of Psychology, 101*(1), 111–130.

Bach, S., Brandeis, D., Hofstetter, C., Martin, E., Richardson, U., & Brem, S. (2010). Early emergence of deviant frontal fMRI activity for phonological processes in poor beginning readers. *Neuroimage*, *53*(2), 682-693.

Bach, S., Richardson, U., Brandeis, D., Martin, E., & Brem, S. (2013). Print-specific multimodal brain activation in kindergarten improves prediction of reading skills in second grade. *Neuroimage*.

Bara, F., Gentaz, E., Colé, P., Sprenger-Charolles, L. (2004). The visuo-haptic and haptic exploration of letters increases the kindergarten-children's understanding of the alphabetic principle. *Cognitive Development, 19*(3), 433–449.

Baretta, L., Tomitch, L. M. B., Lim, V. K., & Waldie, K. E. (2012). Investigating reading comprehension through EEG. *Ilha do Desterro A Journal of English Language, Literatures in English and Cultural Studies*, (63), 069-100.

Baumert, J., & Kunter, M. (2006). Stichwort: Professionelle Kompetenz von Lehrkräften. Zeitschrift für Erziehungswissenschaft, 9, 469-520.

Baumert, J., Kunter, M., Blum, W., Brunner, M., Voss, T., Jordan, A. et al. (2010). Teachers' mathematical knowledge, cognitive activation in the classroom, and student progress. American Educational Research Journal, 47(1), 133-180.

Berliner, D. C. (2001). Learning about and learning from expert teachers. Educational Research 35, 463-482.

Berliner, D.C. (2004). Describing the behavior and documenting the accomplishments of expert teachers. Bulletin of Science, Technology and Society, 24(3), 200-212.

Bolger DJ, Perfetti CA, Schneider W (2005) Cross-cultural effect on the brain revisited: Universal structures plus writing system variation. *Human Brain Mapping, 25*(1),92–104.

Bortfeld, H., Fava, F. & Boas, D.A. (2009). Identifying cortical lateralization of speech processing in infants using near-infrared spectroscopy. *Developmental Neuropsychology, 34,* 52-65.

Brem, S., Bach, S., Kucian, K., Guttorm, T. K., Martin, E., Lyytinen, H., ... & Richardson, U. (2010). Brain sensitivity to print emerges when children learn letter–speech sound correspondences. *Procedings of the National Academy of Sciences*, *107*(17), 7939-7944.

Brennan, J., Nir, Y., Hasson, U., Malach, R., Heeger, D. J., & Pylkkänen, L. (2012). Syntactic structure building in the anterior temporal lobe during natural story listening. *Brain and Language*, *120*(2), 163-173.

Bromme, R. (1992). Der Lehrer als Experte: zur Psychologie des professionellen Wissens. Bern: Huber.

Bromme, R. (2008). Lehrerexpertise. In W. Schneider & M. Hasselhorn (Hrsg.). Handbuch der Pädagogischen Psychologie (S. 159-167). Göttingen: Hogrefe.

Brunelliere, A., Sanchez-Garcia, C., Ikumi, N. & Soto-Faraco, S. (2013) Visual information constrains early and late stages of spoken-word recognition in sentence context. *International Journal of Psychophysiology 89*(1), 136-147.

Bruner, J. T. (1997). Education and the brain: a bridge too far. Educational Researcher, 26, 4–16.

Bukova-Güzel, E. (2010). An investigation of pre-service mathematics teachers' pedagogical content knowledge, using solid objects. Scientific Research and Essays, 5(14), 1872-1880.

Buonomano, D. V, & Merzenich, M. M. (1998). Cortical plasticity: from synapses to maps. Annu Rev Neurosci, 21, 149–186. doi:10.1146/annurev.neuro.21.1.149

Burden, K., Younie, S. and Leask, M. (2013). Translational research principles applied to education: the mapping educational specialist knowhow (MESH) initiative. Journal of Education for Teaching. 39 (4), 459-463.

Capel, S., Bassett, S., Newton, A. and Zwozdiak-Myers, P. (forthcoming). Lesson Planning Research Project: Interim report. Brunel University, UK.

Casey, B. J., Giedd, J. N., & Thomas, K. M. (2000). Structural and functional brain development and its relation to cognitive development. Biol Psychol, 54(1-3), 241–257. Retrieved from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11035225

Cohen Kadosh, R., Cohen Kadosh, K., Kaas, A., Henik, A., and Goebel, R. (2007). *Neuron 53*, 307–314.

Cohen L, Dehaene S, Vinckier F, Jobert A, Montavont A (2008) Reading normal and degraded words: Contribution of the dorsal and ventral visual pathways. *Neuroimage, 40*(1), 353–366.

Condliffe Lagemann, E. (2000). An Elusive Science: The Troubling History of Education Research. Chicago: University of Chicago Press.

Davis, P. (2008). Syntax and pathways. *Interdisciplinary Science Reviews*, *33*(4), 265-277.

Dehaen, S. (2011). The massive impact of literacy on the brain and its consequences for education. *Human Neuroplasticity and Education*. Pontifical Academy of Sciences, Scripta Varia 17, 201 Available onwww.pas.va/content/dam/accademia/pdf/sv117/sv117-dehaene.pdf

Dehaene S, Cohen L, Sigman M, Vinckier F (2005). The neural code for written words: A proposal. *Trends in Cognitive Science, 9*(7),335–341.

Dehaene, S. (1997). The number sense. Oxford University Press.

Dehaene, S. (2009). *Reading in the brain*. London, UK: Penguin Books.

Dehaene, S. (2013). *Inside the letterbox: How literacy transforms the human brain.* Available from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3704307/

Dehaene, S., Pegado, F., Braga, L.W., Ventura, P., Nunes Filho, G., Jobert, A., *et al.* (2010). How learning to read changes the cortical networks for vision and language. *Science, 330*(6009), 1359-1364.

Dehaene, S., Piazza, M., Pinel, P., & Cohen, L. (2003). Three parietal circuits for number processing. *Cognitive Neuropsychology, 20,* 487-506.

Dekker, S., Lee, N.C., Howard-Jones, P. & Jolles, J. (2012). Neuromyths in Education: Prevalence and Predictors of Misconceptions among Teachers. Frontiers in psychology, 3, 429. doi:10.3389/fpsyg.2012.00429

Depaepe, F., Verschaffel, L., & Kelchtermans, G. (2013). Pedagogical content knowledge: A systematic review of the way in which the concept has pervaded mathematics educational research. Teaching and Teacher Education, 34, 12-25.

Devauchelle, A. D., Oppenheim, C., Rizzi, L., Dehaene, S., & Pallier, C. (2009). Sentence syntax and content in the human temporal lobe: an fMRI adaptation study in auditory and visual modalities. *Journal of Cognitive Neuroscience*, *21*(5), 1000-1012.

Devlin, J.T., Jamison, H.L., Matthews, P.M. & Gonnerman, L.M. (2004). Morphology and the internal structure of words. *Procedings of the National Academy of Sciences, USA 101*(41), 14984–14988.

Dommett, E. J., Devonshire, I. M., Plateau, C. R., Westwell, M. S., & Greenfield, S. A. (2011). From scientific theory to classroom practice. The Neuroscientist a review journal bringing neurobiology neurology and psychiatry, 17, 382–388.

Dubinsky, J. M. (2010). Neuroscience education for prekindergarten-12 teachers. The Journal of neuroscience : the official journal of the Society for Neuroscience, 30(24), 8057–60. doi:10.1523/JNEUROSCI.2322-10.2010

Fair, D.A., Cohen, A.L., Dosenbach, N.U., Curch, J.A., Miezin, F.M., Barch, D.M., Raichle, M.E., Peterssen, S.E. & Schlagger, B.L. (2008) The maturing architecture of the brain's default network. *Procedings of the National Academy of Science USA 105*, 4028–4032.

Fernald, A., & Marchman, V. A. (2012). Individual Differences in Lexical Processing at 18 Months Predict Vocabulary Growth in Typically Developing and Late-Talking Toddlers. *Child Development*, *83*(1), 203-222.

Fox, N. A., Zeanah, C. H., & Nelson, C. A. (2012). Introduction to the special issue on the effects of early experience and stress on brain and behavioral development. *International Journal of Behavioral Development*, *36*(1), 1.

Franceschina F (2005) *Fossilized second language grammars: The acquisition of grammatical gender.* Amsterdam: John Benjamins.

Friederici, A. D. (2011). The brain basis of language processing: From structure to function. *Physiological Reviews, 91*(4), 1357-1392. doi:10.1152/physrev.00006.2011.

Friederici, A. D., Bahlmann, J., Friedrich, R., & Makuuchi, M. (2011). The neural basis of recursion and complex syntactic hierarchy. *Biolinguistics*, *5*(1-2), 087-104.

Gathercole, S. E., & Baddeley, A. D. (1990). Phonological memory deficits in language disordered children: Is there a causal connection?. *Journal of Memory and Language*, *29*(3), 336-360.

Gazzaniga, M. S., Ivry, R. B., & Mangun, G. R. (2008). Cognitive Neuroscience: The Biology of the Mind (Third Edit.). New York: WW. Norton & Company, Inc. .

Gebauer D, Fink A, Kargl R, Reishofer G, Koschutnig K, et al. (2012) Differences in Brain Function and Changes with Intervention in Children with Poor Spelling and Reading Abilities. *PLoS ONE 7*(5): e38201. doi:10.1371/journal.pone.0038201

Gentner, D. *(*2003*)*. Why we're so smart*. In* D.Gentner *&* S.Goldin-Meadow *(Eds.), Language in mind: Advances in the study of language and thought (pp. 195–235). Cambridge, MA: MIT Press.*

Gentner, D. (2010). Bootstrapping the mind: Analogical processes and symbol systems. *Cognitive Science*, *34*(5), 752-775.

Gentner, D*., &* Medina, J. *(*1998*)*. Similarity and the development of rules*. Cognition, 65,* 263–297*.*

Graves, W. W., Desai, R., Humphries, C., Seidenberg, M. S., & Binder, J. R. (2010). Neural systems for reading aloud: a multiparametric approach. *Cerebral Cortex*, *20*(8), 1799-1815.

Grossman, P. L. (1990). The making of a teacher: Teacher knowledge and teacher education. New York: Teachers College Press.

Grossman, P. L. & Richert, A. E. (1988). Unacknowledged Knowledge Growth: A Re-Examination of the Effects of Teacher Education. Teaching and Teacher Education, 4(1), 53-62.

Grossman, T., Striano, T. & Frederici, A.D. (2005)*. Infants' electric brain responses to emotional prosody. Neuroreport, 16,* 1825-1828.

Goswami, U. (2006). Neuroscience and education: from research to practice? Nature Reviews Neuroscience, 7(5), 406–411. Retrieved from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=16607400

Greenough, W. T., Black, J. E., & Wallace, C. S. (1987). Experience and brain development. Child Development, 58, 539–559.

Hackman, D. A., Farah, M. J., & Meaney, M. J. (2010). Socioeconomic status and the brain: mechanistic insights from human and animal research. Nature Reviews Neuroscience, 11, 651–659.

Hargreaves, D. and Hopkins, D. (1991). The Empowered School: The Management and Practice of Development Planning, London: Cassell.

Hattie, J. (2009). Visible learning: A synthesis of over 800 meta-analyses relating to achievement. International Review of Education (Vol. 57, p. 378). doi:10.1007/s11159-011-9198-8

Henderson, L. M., Baseler, H. A., Clarke, P. J., Watson, S., & Snowling, M. J. (2011). The N400 effect in children: Relationships with comprehension, vocabulary and decoding. *Brain and Language*, *117*(2), 88-99.

Hickok, G. & Poeppel, D. (2000). Towards a functional neuroanatomy of speech perception. *Trends in Cognitive Science, 4,* 131-138.

Hill, N. M., & Schneider, W. (2006). Brain changes in the development of expertise: Neuroanatomical and neurophysiological evidence about skill-based adaptations. *The Cambridge handbook of expertise and expert performance*, 653-682.

Howard-Jones, P. A. (2011). A Multiperspective Approach to Neuroeducational Research. Educational Philosophy and Theory, 43, 24–30. doi:10.1111/j.1469-5812.2010.00703.x

Hu W, et al. (2010) Developmental dyslexia in Chinese and English populations: Dissociating the effect of dyslexia from language differences. *Brain, 133*(Pt 6), 1694–1706.

Illes, J., Moser, M. A., McCormick, J. B., Racine, E., Blakeslee, S., Caplan, A., … Weiss, S. (2010). Neurotalk: improving the communication of neuroscience research. Nature reviews. Neuroscience, 11(1), 61–9. doi:10.1038/nrn2773

John, P. D. (2006). Lesson planning and the student teacher: re-thinking the dominant model, Journal of Curriculum Studies, 38 (4) 483–498.

Johnson, M. H. (2001). Functional brain development in humans. Nat Rev Neurosci, 2(7), 475–483. Retrieved from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11433372

Kennedy, M. (1999). The role of preservice teacher education. Teaching as the learning profession: Handbook of policy and practice, 54-85.

Kharitonova, M., Martin, R. E., Gabrieli, J. D., & Sheridan, M. A. (2013). Cortical gray-matter thinning is associated with age-related improvements on executive function tasks. *Developmental Cognitive Neuroscience*.

Kim, C., & Pekrun, R. (2014). Emotions and motivation in learning and performance. In *Handbook of research on educational communications and technology* (pp. 65-75). New York, NY: Springer.

König, J., Blömeke, S., Paine, L., Schmidt, B. & Hsieh, F-J. (2011). General Pedagogical Knowledge of Future Middle School Teachers. On the Complex Ecology of Teacher Education in the United States, Germany, and Taiwan. Journal of Teacher Education, 62, 188-201.

König, J. , Buchholtz, C. and Dohmen, C. (submitted). Lesson Plan Analysis: Empirical Findings on Future Teachers' Competence to Plan a Lesson. Zeitschrift für Erziehungswissenschaft.

Koyama, M. S., Di Martino, A., Zuo, X. N., Kelly, C., Mennes, M., Jutagir, D. R., ... & Milham, M. P. (2011). Resting-state functional connectivity indexes reading competence in children and adults. *The Journal of Neuroscience*, *31*(23), 8617-8624.

Kuehne, S. E., Gentner, D., & Forbus, K. D. (2000). Modeling infant learning via symbolic structural alignment. *In* L. R.Gleitman & A. K.Joshi *(Eds.), Proceedings of the twenty-second annual conference of the Cognitive Science Society, (pp. 286–291). Mahwah, NJ: Erlbaum*

Lauro, L. J. R., Reis, J., Cohen, L. G., Cecchetto, C., & Papagno, C. (2010). A case for the involvement of phonological loop in sentence comprehension. *Neuropsychologia*, *48*(14), 4003-4011.

La Velle, L. and Leask, M. (submitted) Professionalism and Masterliness in Education: a call for action to meet the challenges of the information age. Journal of the Teacher Education Advancement Network.

Leask, M. (2011). Improving the Professional Knowledge base for Education: Using knowledge management and Web 2.0 tools. Policy Futures in Education. Volume 9 Number 5 www.wwwords.co.uk/PFIE.

Lee, C. H. (2009). Testing the role of phonology in reading: Focus on sentence processing. *Journal of Psycholinguistic Research*, *38*(4), 333-344.

Lee, K. H., & Siegle, G. J. (2012). Common and distinct brain networks underlying explicit emotional evaluation: a meta-analytic study. *Social Cognitive and Affective Neuroscience*, *7*(5), 521-534.

Loewenstein, J., & Gentner, D. (2005). Relational language and the development of relational mapping. *Cognitive Psychology, 50,* 315–353.

Longcamp, M., Anton, J.L., Roth, M., Velay, J.L. (2003). Visual presentation of single letters activates a premotor area involved in writing. *Neuroimage ,1*9(4),1492–1500.

MacGregor, L. J., Pulvermüller, F., van Casteren, M., & Shtyrov, Y. (2012). Ultra-rapid access to words in the brain. *Nature Communications*, *3*, 711.

Malter Cohen, M., Tottenham, N., & Casey, B. J. (2013). Translational developmental studies of stress on brain and behavior: Implications for adolescent mental health and illness?. *Neuroscience*.

Manizade, A.G. & Mason, M.M. (2011). Using Delphi methodology to design assessments of teachers' pedagogical content knowledge. DOI 10.1007/s10649-010-9276-z

Mårtensson, J., Eriksson, J., Bodammer, N. C., Lindgren, M., Johansson, M., Nyberg, L., & Lövdén, M. (2012). Growth of language-related brain areas after foreign language learning. *NeuroImage*.

May, A. (2011). Experience-dependent structural plasticity in the adult human brain. Trends Cogn Sci, 15, 475–482.

McVay, J. C., & Kane, M. J. (2012). Why does working memory capacity predict variation in reading comprehension? On the influence of mind wandering and executive attention. *Journal of Experimental Psychology: General*, *141*(2), 302.

Minagawa-Kawai, Y., Mori, K., Naoi, N. & Kojima, S. (2007*). Neural attunement processes in infants during the acquisition of a language-specific phonemic contrast. Journal of Neuroscience, 27,* 315-321.

Minagawa-Kawai, Y., van der Lely, H., Ramus, F., Sato, Y., Mazuka, R., & Dupoux, E. (2011). Optical brain imaging reveals general auditory and language-specific processing in early infant development. *Cerebral Cortex*, *21*(2), 254-261.

Mishra, P., & Koehler, M. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. The Teachers College Record, 108(6), 1017-1054.

Mishra, P., & Koehler, M. (2009). Too Cool for School? No Way! Using the TPACK Framework: You Can Have Your Hot Tools and Teach with Them, Too. Learning & Leading with Technology, 36(7), 14-18.

Morein-Zamir, S., & Sahakian, B. J. (2010). Neuroethics and public engagement training needed for neuroscientists. Trends in cognitive sciences, 14(2), 49–51. doi:10.1016/j.tics.2009.10.007

Moro, A. (2013). *The equilibrium of human syntax: Symmetries in the brain*. London, UK: Routledge.

Munakata, Y., Casey, B. J., & Diamond, A. (2004). Developmental cognitive neuroscience: progress and potential. Trends in Cognitive Sciences, 8(3), 122–128. Retrieved from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=15301752

Nakamura K, Dehaene S, Jobert A, Le Bihan D, Kouider S (2007) Task-specific change of unconscious neural priming in the cerebral language network. *Procedings of the National Academy of Sciences, USA 104*(49), 19643–19648.

Nakamura, K., Kuo, W. J., Pegado, F., Cohen, L., Tzeng, O. J., & Dehaene, S. (2012). Universal brain systems for recognizing word shapes and handwriting gestures during reading. *Proceedings of the National Academy of Sciences*, *109*(50), 20762-20767.

Nevo, E., & Breznitz, Z. (2012). The development of working memory from kindergarten to first grade in children with different decoding skills. *Journal of experimental Child Psychology*.

Noble, K. G., Wolmetz, M. E., Ochs, L. G., Farah, M. J., & McCandliss, B. D. (2006). Brain-behavior relationships in reading acquisition are modulated by socioeconomic factors. Developmental Science, 9(6), 642–654. Retrieved from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17059461

OECD (2003). New Challenges for Educational Research, Paris. Ceri. http://www.oecd-ilibrary.org/education/new-challenges-for-educational-research_9789264100312-en;jsessionid=6arr066mkpq1d.x-oecd-live-02 Accessed 26 October 2013.

OECD. (2002). Understanding the Brain: Towards a New Learning Science. Paris: OECD Publishing.

Pallier, C., Devauchelle, A. D., & Dehaene, S. (2011). Cortical representation of the constituent structure of sentences. *Proceedings of the National Academy of Sciences*, *108*(6), 2522-2527.

Panizza, D. (2012). Formal Neurosemantics. Logic, meaning and composition in the Brain. *Journal of Neurolinguistics*, *25*(5), 460-488.

Parrila, R., Kirby, J. R., & McQuarrie, L. (2004). Articulation rate, naming speed, verbal short-term memory, and phonological awareness: Longitudinal predictors of early reading development?. *Scientific Studies of Reading*, *8*(1), 3-26.

Peña, M., Maki, A., Kovacic, D., Dehaene-Lambertz, G., Koizumi, H., Bouquet, F. & Mehler, J. (2003). Sounds and silence: an optical topography study of language recognition at birth. *Proc Natl Acad* Sci USA, 100, 11702-11705

Piazza, M., Pinel, P., Le Bihan, D., & Dehaene, S. (2007). A magnitude code common to numerosities and number symbols in human intraparietal cortex. *Neuron*, *53*(2), 293-305.

Pickering, S. J., & Howard-Jones, P. (2007). Educators' Views on the Role of Neuroscience in Education: Findings From a Study of UK and International Perspectives. Mind Brain and Education, 1, 109–113. doi:10.1111/j.1751-228X.2007.00011.x

Plaza, M., & Cohen, H. (2003). The interaction between phonological processing, syntactic awareness, and naming speed in the reading and spelling performance of first-grade children. *Brain and Cognition*, *53*(2), 287-292.

Prat, C. S. (2011). The brain basis of individual differences in language comprehension abilities. ***Language and Linguistic Compass***, *5*(9), 635-649.

Prat, C. S., Mason, R. A., & Just, M. A. (2012). An fMRI investigation of analogical mapping in metaphor comprehension: The influence of context and individual cognitive capacities on processing demands. ***Journal of Experimental Psychology: Learning, Memory, and Cognition***, *38*, 282-94.

Price, C.J. (2000). The anatomy of language: Contributions from functional neuroimaging. *Journal of Anatomy, 197*(Pt 3),335–359.

Procter, R. (forthcoming). Teaching as an evidence informed profession: teacher education and knowledge mobilisation with a focus on digital technology. Unpublished PhD dissertation, University of Bedfordshire, UK.

Pulvermüller, F. (2010). Brain embodiment of syntax and grammar: Discrete combinatorial mechanisms spelt out in neuronal circuits. *Brain and Language*, *112*(3), 167-179.

Pulvermüller, F., & Knoblauch, A. (2009). Discrete combinatorial circuits emerging in neural networks: a mechanism for rules of grammar in the human brain?. *Neural Networks*, *22*(2), 161-172.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning. Educational Researcher, 29, 4–15.

Rapp, B., & Lipka, K. (2011). The literate brain: The relationship between spelling and reading. *Journal of Cognitive Neuroscience*, *23*(5), 1180-1197.

Rayner, K. (2009). Eye movements in reading: Models and data. *Journal of Eye Movement Research*, *2*(5), 1.

Richardson, F. M., Thomas, M. S., Filippi, R., Harth, H., & Price, C. J. (2010). Contrasting effects of vocabulary knowledge on temporal and parietal brain structure across lifespan. *Journal of cognitive neuroscience*, *22*(5), 943-954.

Roux, F.E., et al. (2009). The graphemic/motor frontal area Exner's area revisited. Ann *Neurology, 66*(4), 537–545.

Sato, H., Hirabayashi, Y., Tsubokura, S., Kanai, M., Ashida, S., Konishi, I., Uchida, M., Hasegawa, T., Konishi, Y. & Maki, A. (2006). Cortical activation in newborns while listening to sounds of mother tongue and foreign language: an optical topography study. *Proceeding of International Conference on Infant Studies, Kyoto, Japan. Presentation number 037-070.*

Schilbach, L., Bzdok, D., Timmermans, B., Fox, P. T., Laird, A. R., Vogeley, K., & Eickhoff, S. B. (2012). Introspective minds: using ALE meta-analyses to study commonalities in the neural correlates of emotional processing, social & unconstrained cognition. *PLoS One*, *7*(2), e30920.

Schon, D. (1983). The Reflective Practitioner: how professionals think in action. London: Temple Smith.

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

Shulman, L. S. (1986). Those Who Understand: Knowledge Growth in Teaching. Educational Researcher, 15(2), 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. Havard Educational Research, 57, 1-22.

Stein, M., Federspiel, A., Koenig, T., Wirth, M., Strik, W., Wiest, R., ... & Dierks, T. (2012). Structural plasticity in the language system related to increased second language proficiency. *Cortex*, *48*(4), 458-465.

Szucs, D., & Goswami, U. (2007). Educational neuroscience: Defining a new discipline for the study of mental representations. Mind, Brain and Education, (1), 3.

Tatto, M. T., Schwille, J., Senk, S., Ingvarson, L., Rowley, G., Peck, R., Bankov, K., Rodriguez, M., & Reckase, M. (2012). Policy, practice, and readiness to teach primary and secondary mathematics in 17 countries. Findings from the IEA teacher education and development study in mathematics (TEDS-M). Retrieved April 10, 2012, from http:// www.iea.nl/fi leadmin/user_upload/Publications/Electronic_versions/IEA_TEDS-M.pdf

Tettamanti, M., Rotondi, I., Perani, D., Scotti, G., Fazio, F., Cappa, S. F., & Moro, A. (2009). Syntax without language: Neurobiological evidence for cross-domain syntactic computations. *Cortex*, *45*(7), 825-838.

Thierry, G., Martin, C. D., Gonzalez-Diaz, V., Rezaie, R., Roberts, N., & Davis, P. M. (2008). Event-related potential characterisation of the Shakespearean functional shift in narrative sentence structure. *Neuroimage*, *40*(2), 923-931.

Tokuhama-Espinosa, T. (2011). Mind, brain, and education science: A comprehensive guide to the new brain-based teaching. Mind brain and education science.

Turkeltaub, P. E., Gareau, L., Flowers, D. L., Zeffiro, T. A., & Eden, G. F. (2003). Development of neural mechanisms for reading. *Nature Neuroscience*, *6*(7), 767-773.

van Atteveldt, N., Formisano, E., Goebel, R., Blomert, L. (2004). Integration of letters and speech sounds in the human brain. *Neuron, 43*(2), 271–282.

van den Broek, G. S., Takashima, A., Segers, E., Fernández, G., & Verhoeven, L. (2013). Neural Correlates of Testing Effects in Vocabulary Learning. *NeuroImage*.

Van Overwalle, F. (2009). Social cognition and the brain: A meta-analysis. *Human Brain Mapping*, *30*(3), 829-858.

Veal, W. R., & MaKinster, J. G. (1999). Pedagogical content knowledge taxonomies. Electronic Journal of Science Education, 3(4).

Vespignani, F., Canal, P., Molinaro, N., Fonda, S., & Cacciari, C. (2010). Predictive mechanisms in idiom comprehension. *Journal of Cognitive Neuroscience*, *22*(8), 1682-1700.

Vouloumanos, A. & Werker, J.F. (2007). Listening to language at birth: evidence for a bias for speech in neonates. *Developmental Science, 10,* 159-164.

Vul, E., Harris, C., Winkielman, P., & Pashler, H. (2009). Puzzlingly high correlations in fMRI studies of emotion, personality, and social cognition. *Perspectives on Psychological Science*, *4*(3), 274-290.

White EJ, Genesee F, Steinhauer K (2012) Brain Responses before and after Intensive Second Language Learning: Proficiency Based Changes and First Language Background Effects in Adult Learners. PLoS ONE 7(12): e52318. doi:10.1371/journal.pone.0052318

Wildgruber, D., Pihan, H., Ackerman, H. Erb, M. & Grodd, W. (2002). Dynamic brain activation during processing of emotional intonation: influence of acoustic parameters, emotional valence, and sex. *Neuroimage, 15,* 856-869.

Wolf, M. (2007). *Proust and the squid: The story and science of the reading brain*. New York: Harper.

Zatorre, R.J. & Gandour, J.T. (2008). Neural specializations for speech and pitch: moving beyond the dichotomies. *Philos Trans R Soc Lond B Biol Sci. 363*, 1087-1104.