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Studies in Exceptionality and the Connectivity of Mathematics

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Abstract

Mathematics education is complicated by issues related to cohesion and connectivity within the subject, and in its relationships to other subjects, and these issues are reflected in studies of exceptionality in mathematics. Some recent studies have argued that consideration of the connectivity of mathematics as a subject may benefit from an emphasis on broad approaches to studies of mathematics within generalist models of cognition, including approaches based in modern scientific research and recent studies of networks and complexity. This paper explores the contribution that studies in exceptionality have made in resolving the issue of connectivity in mathematics, and examines efforts being made for a more unified conceptualisation of the subject through broad approaches. A description of learning and memory, based in a novel information framework, is explored as a basis for a generalist cognitive model which may accommodate mathematics concepts within a broader educational context. This model may provide insights into the examination of the connectivity of mathematics as well as methods for teaching the subject in modern educational institutions.

Keywords: exceptionality, mathematics, connectivity, biology, complexity

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Introduction

In modern educational institutions, such as schools and universities, one of the primary goals of teaching students is to optimise and facilitate a gain in their expertise or achievement and align this with the requirements of a modern curriculum. The development of the curricula used in such institutions has been essentially through teaching practices influenced by the requirements of trade-based economics in industrialised societies (OECD, 2003). Such curricula are a major component of education, with stand-alone subjects allied to the two main curriculum streams, the social and behavioural sciences and the natural sciences, that diverged during the industrial revolution. The current broad and diverse range of subjects is due, in part, to the development that has followed industrial and technological and associated economic change (OECD, 2003). This has led to the historical partition of subjects into categories and the partition also of these categories into learning stages, such as seen in the concepts of Piaget (1928, in Huitt & Hummel, 2003).

Despite the emphasis given to mathematics in some societies, the historical development of the subject appears to have contributed to the development of issues that relate to a lack of cohesiveness within the subject as taught in modern educational institutions (Mowat & Davis, 2010). Some of these issues are evident in the lack of accommodation of studies from modern research in the development of strategies that may target education, specifically with regard to integrative biology[1] (Fischer et al., 2010), as well as in the widely differing, sometimes highly critical, reactions to modern theoretical research perspectives (Howard-Jones, 2008). Issues of cohesiveness are reflected in studies of exceptionality in mathematics, where modern scientific research perspectives have been largely ignored or disputed (Geake, 2009) and where differing theoretical approaches to education may be based in concepts and assumptions that appear to bear little relation to each other (Zeigler & Phillipson, 2012). This paper, therefore, examines studies of high levels of expertise in mathematics and argues, based on this examination, that a generalised approach to cognition may provide some insight into issues of cohesiveness in mathematics education. This paper outlines an overarching framework that may be applied to such a generalised approach.

Diversity in Modern Mathematics and High Levels of Expertise

Mathematics as taught in modern educational institutions has followed industrial and technological and associated economic change and a consequent demand for people with education in numeracy or mathematical literacy, even where this is confined to simple arithmetic calculations and the making or auditing of measurements (OECD, 2003). In such institutions, this demand has

[1]Integrative biology is a term used to describe collectively the disciplines, including neuroscience, that relate to studies of organisms, including humans.

led to the development of the subject of mathematics that has been divided, in theory at least, into categories that relate the application of mathematical ideas to the solving of real-world problems[1] in a variety of differing areas, such as taxation and commerce, land measurement and astronomy, and to measurement of change more generally (Kline, 1996). These categories, with some minor differences, are used widely and are perhaps best reflected in the test categories for the OECD Program for International Student Assessment (PISA) in mathematics (OECD, 2003), as a combination of: *quantity*, including numeric phenomena as well as quantitative relationships and patterns; *space and shape*, including spatial and geometric phenomena and relationships as well as some measurement; *change and relationships*, including algebra and; *uncertainty*, including probability and statistics. It is this very diversity that appears to prevent adequate comparisons of assessments within and across the separate categories within the subject, and this is perhaps best illustrated by the assertion that the results from worldwide comparative assessment of mathematics in such schemes as PISA may be invalid (Hanushek & Woessmann, 2010).

In studies of exceptionality in mathematics there is also disagreement about empirical, or even descriptive, comparisons of performance across cohorts in the many diverse categories of the subject (Butterworth, 2006). As is the case in mathematics more generally, assessments of expert performance in mathematics are largely norm-referenced, with standardised intelligence tests, competitions, or other types of performance assessments conducted with this in mind (Vialle & Rogers 2009). Some such assessments may be used to grade individuals for various reasons, for example, in order to assign monetary or other incentive awards in competitions and also to place students in ability groupings in mathematics more generally. Such performance assessments are not always used in any directly formative way, although they may be used to indicate progress towards a goal of increased expertise or expert knowledge, for example, through guided practice (Ericsson, Nandagopal & Roring, 2009). In educational institutions, such assessments may serve as a guide to the quality and content of education that is provided to some students within subjects or within year groups and, recently at least, have been used to determine the allocation of resources, including an improved teacher to student ratio, to individual students or groups of students, and this includes those students gifted in mathematics (Vialle & Rogers, 2009).

With regard to the evaluation of high levels of expertise, the difficulties in comparison may be exacerbated by the single use of test instruments without any later verification, either with or without intervention, or without adequate teaching in the case of formative assessments (Geake, 2009). So-called mathematics aptitude and intelligence tests that have a mathematics component (Geake, 2009), are sometimes used in identifying giftedness in mathematics,

[1]The term “solving of problems” is used here in the sense, say, of solving a written mathematical problem (e.g., see Sweller, 1988) and is not to be confused in with the term “problem solving” which is reserved here for use in a context related to such functions of the central nervous system as attention and working memory.

but appear to be problematic if there is no correlation longitudinally between results in such tests and results achieved in mathematics taught in an educational institution (Ericsson et al., 2009). This complex situation is given added dimension by arguments about whether educational institutions can function effectively in the educational development of the gifted (Freeman, 2006) and by the view that studies of gifted performance in mathematics specifically may be directed only at the aspects of mathematics that are determined as valuable in a particular society, depending on who is making such determinations and on their rationale for any such determination (Kaufman & Sternberg, 2008).

While some of these complexities may be observed in mathematics education, and in subject teaching more generally, there is little in the way of intersection between studies of gifted performance in mathematics and studies of the broad range of performance in mathematics across student cohorts. Studies of giftedness in mathematics, for example, are not generally inclusive of the mathematics student population at large, since such studies are identifying and examining only a particular cohort within that population. Some studies of giftedness do indicate, however, that there is a need for a framework within which to compare studies of high levels of expertise, including mathematical giftedness, so that an overarching conceptualisation may be developed of giftedness as an aspect of cognition and behaviour (Kaufman & Sternberg, 2008). This situation reflects that seen in mathematics education, and education more generally, and it has been argued that such an overarching conceptualisation may be both useful and necessary for the comparison of performance both within and across teaching subjects (Samuels 2009). The following section argues that modern integrative biology appears to offer a way forward, and that studies of giftedness undertaken within the constraints of modern empirical science appear to point the way towards a unified theoretical conceptualisation of cognition that may embrace mathematics and giftedness.

Mathematics Achievement and Integrative Biology

In mathematics, high levels of expertise gained through learning are assessed in the same way that expertise is assessed more generally, through observation of performance, with the types of performance varying from simple eye blinks to the sometimes complex sequences of movement seen in such activities as talking, reading and writing, and sports performances. Studies in integrative biology have demonstrated that such performance is based in muscular contractions that relate to environmental interactions and storage of information in memory (Llinás, 2001). Learning and memory processes and their relationship to performances (motor tasks) have been the subject of considerable recent research both in the natural sciences and the social and behavioural sciences, and some of this research has been directed at examining individuals who demonstrate above-normal performances that are valued in particular societies (Cotterill, 2001; Mottron, Dawson & Soulières, 2009). Such performances include those demonstrating the above-normal expertise seen on the concert platform, in the chess arena, and on the sporting field, at various levels from local and national through to international, and include also those that exceed the normal in pen and paper tests, such as in the Mathematics Olympiads (Zhu, 2007).

As well as research into examining comparative performance, there has been also research into the determination of potential future performance, with support obtained for the effectiveness of some such determinations, for example, in assessments used to assess potential high ability in mathematics and to assist in development of training regimes (O'Boyle, 2005). Although results from some assessments used to determine potential academic ability, such as intelligence quotient (IQ), spatial intelligence, or crystallised intelligence assessments, have been correlated with academic performance in mathematics, studies in integrative biology have indicated that there are limitations in applying such results to programs designed to increase expertise (Haier, 2009). Haier and associates (e.g., Haier & Jung, 2008) have, however, developed a parieto-frontal integration theory (P-FIT) that correlates the amount of grey matter (neuronal cell bodies), activated across a number of different brain regions, with test scores from several such assessments, and this model may be useful in determining general intelligence based on the brain's measurable characteristics. There may be, however, many other factors that may play a role in both performance and ability (Samuels, 2009), with processing time, which is linked to white matter (neuronal connections), also likely to play a key role in any assessment of potential intelligence (Haier, 2009).

It has been difficult to relate giftedness, including giftedness in mathematics, to specific genetic attributes and Plomin and associates (Davis et al., 2007) have suggested that this is because the genes that contribute to superior learning and memory and related performances, may be generalist genes that contribute to development of many parts of the human organism. Further, some research in integrative biology has indicated that learning and memory may not be subject-specific, being related to general attributes of a human cortical advantage, such as an ability to generalise, attentional or working memory processes, or ability in problem solving (Dehaene, 2007, 2009; Goswami, 2008). Although executive function, including working memory (short-term memory) and related inhibitory processes, has been implicated specifically in mathematics performances (Bull, 2008), this may be largely because such processes relate to generalised skills that are concerned with the utilisation of strategies. Some researchers in integrative biology have, in fact, related superior working memory and attention to high scores in assessments of the general factor of intelligence (*g* factor) or fluid intelligence (Haier, 2009), and this superior functionality has been considered a neuropsychological characteristic of gifted people (Geake, 2009). Such neuronal processes appear to be related also to creativity, adding support to the suggested relationships between intelligence, giftedness, and creativity

(Cotterill, 2001). None of these features, however, has been correlated exclusively with high levels of mathematics expertise.

Some recent studies in integrative biology have attempted to describe fully the neuronally-based pattern analysis carried out during mathematics by comparing brain function in individuals who have savant syndrome, including individuals with autism spectrum disorder, with that of individuals described as neurotypical, where both groups were considered as gifted in mathematics (Happé & Vital, 2009). Some studies (Mottron et al., 2009) have indicated that the detection, integration and completion of patterns, and the requisite grouping processes, function primarily in the negotiation of the phenomenological world. In association with this pattern analysis is the ability to produce new material within the constraints of the integrated structure, a process Mottron et al. (2009) refer to as creativity. In gifted individuals who are neurotypical, this integrated structure may be determined by automatic hierarchies that govern generalisation and memory processing through information loss and the limitation of the role of perception, although this may not be the case with savant syndrome. Grandin (2009), a noted researcher who has autism and savant syndrome, has argued that the orientation towards pattern analysis that may be recognised as mathematics, as well as resulting from environmental interaction, may be due also to differences in connectivity within individuals.

A better understanding of pattern analysis as a component of mathematics is, obviously, an important issue in understanding performance in mathematics, including exceptional performance. Snyder and associates (Snyder & Mitchell, 1999) have suggested, however, that the algebraic and algorithmic patterns and processes taught in mathematics may not correspond to the biological patterns and processes that they are designed to activate, and this is supported by Baars (1995) in proposing that human neural systems use heuristic processes and analogies, rather than algorithmic processes, in dealing with patterns of environmental input. Although several capacities have been described for the brain, for example, problem-solving, decision-making and action control, Baars considers that one of the strengths of the brain, and the entire nervous system, may be in remembering and cross-analysing patterns observed from the real world, which is arguably a mathematical capacity. There may be, as well, cross-domain learning processes, with Lakoff and others (e.g., Lakoff & Núñez, 2000) referring to commonality of learning processes in terms of conceptual metaphors, cross-domain mappings that preserve inferential structure and which are essential for linking conceptualisations generally, but which serve also for linking conceptualisations within mathematics as well as in linking mathematics with other subject categories. The view that human learning and memory in specific subjects, such as mathematics, may result from generalist cognitive processes, indicates that a broad cognitive framework may be useful in education and teaching, both in general and within subject categories such as mathematics, and the next section examines the development of such a framework based within the constraints of integrative biology and empirical science.

Towards a Broad Framework for Cognition

There have been studies conducted within integrative biology that have investigated overarching conceptualisations of cognition (Squire & Kandel, 2008), including the investigation of high-level performance within such conceptualisations (Ziegler & Phillipson, 2012). Some such studies have attempted to incorporate an evolutionary perspective in order to place human cognition in a context of changing human interaction with environment and human cultural accumulation, and this has sometimes involved describing aspects of behaviour, such as social interaction and language, in scientific terms (Margoliash & Nusbaum, 2009). The insights determined from such studies are being applied to education through combinations of integrative biology, cognitive psychology and information science (Sweller, 2007). Evolutionary perspectives on learning and memory that are based in integrative biology have been related also to connectivity of processes and pathways in organismal and non-organismal structures and systems (Barabási, 2002; Sporns, 2010) and these studies have, in turn, been applied in generalist studies of cognition and applied to education and mathematics, for example, through the use concepts of embodiment (Lakoff & Núñez, 2000) and its application to the examination of mathematical cohesiveness through complexity theory (Mowat & Davis, 2010).

It is studies of embodiment, in fact, and studies of connectivity of processes and pathways of learning and memory (Barabási, 2002), that have paved the way for the development of an overarching, scientific approach to learning and memory (Woolcott, 2011). This approach has facilitated the development of a broad framework within which to examine cognition more generally, and within which to examine giftedness and mathematics more specifically. In this framework all matter and energy is described as information and all discrete structures within the matter and energy universe (in the sense of Gribbin, 1994) are described as information processing systems. Changes in information within such structures are described as processing[1]. Memory is described in terms of the overarching range of possibilities or potentialities of any matter and energy within such information processing systems, and learning is described as any change that results from input or output of information.

A Generalist Cognitive Model within the Novel Framework

Within this novel framework, a human can be considered as a discrete matter and energy entity and human connectivity can be considered in terms of interactions with environment of the human information processing system and, as well, any designated structure within the human system can be

[1]The concept of information processing here embraces concepts such as building or constructing information (e.g., Fischer, 2009) or growing information pathways as neuronal connections (e.g., Edelman, 1987).

considered also as a similarly discrete entity. On this basis a generalist cognitive model can be used to describe human learning and memory as a function of human connectivity with environment, as well as a function of connectivity within the central nervous system and, in particular, of neuronal connectivity within the brain. This model supports the consideration separately of the differing aspects of human cognition within a dynamic system, and allows also a formalisation of the partitioning of cognitive structures, which is, in practice, a common method in dealing with learning and memory in cognitive psychology and integrative biology. Such dynamism is considered to operate, for example, during storage of discrete information in long-term memory, and in spatiotemporal sequencing of memories (Postle, 2006) and in the linkage of emotions and chemical reward with learning and memory (LeDoux, 2000). Neuronal patterns develop with an intrinsic and dedicated flexibility that acts to adapt each human to a range of environmental inputs, including input classified as mathematics (Dehaene, 2007).

Since this model supports explanations of cognition couched in terms of the interactions of component systems within the human organism, it supports the view that learned concepts are not necessarily uniquely subject-dependent. It is well known that, even though some regions of brain activation may correspond to concepts described as, say, mathematics or reading, many common brain regions may be activated during processing of information in any subject (Dehaene, 2007, 2009). In considering a human individual as this type of information processing system, there may be differing component systems that may process information in different ways and over different time frames, but which may contribute to an assessable human performance, even if these systems sometimes overlap.

An additional advantage of this generalist cognitive model is that it accommodates the concept of expertise as the acquisition of knowledge in specialised domains in individuals that may otherwise have differences in cognitive connectivity, such as may occur in higher functioning individuals within the autism spectrum (Casanova, 2010). Differences in connectivity between component systems, such as seen in neuronal hyper-connectivity and hyper-plasticity, may lead to the development high levels of expertise or may result in lack of expertise depending on what is being assessed (Markram, Rinaldi & Markram, 2007). The model accommodates also the differences in abilities as explained by Haier and associates in their P-FIT model (e.g., Haier & Jung, 2008; Haier, 2009), since each component of the cognitive system, as described in the P-FIT, can be treated effectively as a separate system in describing information transfer, storage, and recall.

The model may be adaptable also to examination of information pathways that are not linear, such as seen in studies of networks and in complexity theory. Such non-linear approaches have been applied in several areas of educational theory (Davis, Sumara & Luce-Kapler, 2008) and to teaching practices (Stamovlasis & Tasparlis, 2005), as well as to educational leadership (Morrison, 2002) and consideration of complexity theory through the lens of the broad framework may facilitate a move away from the linear approach of learning hierarchies seen in mathematics and other curricula of the modern industrial world (Mowat & Davis, 2010). Such approaches, where these can be applied using the generalist cognitive model within this framework, may generate a more detailed account of information being taught and its basis in prior knowledge through a better understanding of the links that occur between environmental information and the actual physicochemical networks or pathways that are used to store that information. Such a description may facilitate the delineation of the sometimes complex pathways that are the basis of human environmental interactions, arguably the main function of learning and memory (Tonegawa, Nakazawa & Wilson, 2004). In particular, such a description may provide support for the treatment of individuals as learning systems that are adaptive and self-organising as studies in complexity theory suggest (Davis et al., 2008).

Conclusion

The description of learning and memory and educational theories within a single system may prove useful in elucidating education and teaching practices, including those that relate to mathematics, and the overarching framework outlined here supports arguments for broadly contextualised viewpoints as suggested in both studies of gifted education (Butterworth, 2006) and mathematics education (Dehaene, 2007). The development of systems that can be described in terms of the matter and energy pathways may resolve some of the issues related to comparability of differing theoretical approaches to educational theory, either through a determination of whether a theoretical system can be described directly in terms of matter and energy pathways, or as a system analogous to a matter and energy system. In the future, therefore, it may be necessary to re-evaluate the determination of what constitutes mathematics in our culture in order to more fully incorporate knowledge of interacting information processing systems that act naturally across subject areas, particularly as it relates to the high level of expertise that is an expected result of gifted education. These systems may be examined at differing levels of complexity and within different theoretical approaches (Davis et al., 2008), but there may be advantages in aligning pedagogy along scientific lines and within a single integrated framework, such as within the broad framework outlined here. In this way the educational theory and teaching practices of mathematics may respond to the cultural determinations of modern society, from both the social and behavioural sciences and the natural sciences and, at the same time, retain elements of current mathematics curricula in a more cohesive form. Such a theoretical framework may be useful also in the determination of expertise, in particular the determination of high levels of expertise in mathematics that are considered important to modern society.

References

Baars. B. (1995). Can physics provide a theory of consciousness ? A Review of *Shadows of the mind* by Roger Penrose. *Psyche*, *2*(8). http://psyche.cs.monash.edu.au/v2/psyche-2-08-baars.html [1 March 2008].

Barabási, A-L. (2002). *Linked. The new science of networks*. Cambridge: Perseus Press.

Bull, R. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology* 33(3): 205-228.

Butterworth, B. (2006). Mathematical expertise. In K.A. Ericsson, N. Charness, P.J. Feltovitch, & R. Hoffman (eds.), *The Cambridge handbook on expertise and expert performance*, 553-568. Cambridge: Cambridge University Press.

Casanova, M.F. (2010). Cortical organization: Anatomical findings based on systems theory. *Translational Neuroscience* 1(1): 62-71.

Cotterill, R. (2001). Co-operation of the basal ganglia, cerebellum, sensory cerebrum and hippocampus: possible implications for cognition, consciousness, intelligence and creativity. *Progress in Neurobiology* 64: 1-33.

Davis, O.S.P., Y. Kovas, N. Harlaar, P. Busfield, A. McMillan, J. Frances, S.A. Petrill, P.S. Dale & R. Plomin, (2007). Generalist genes and the internet generation: Etiology of learning abilities by web testing at age 10. *Genes, Brain and Behaviour* 7: 455-462.

Davis, B., D.J. Sumara & R. Luce-Kapler (2008). *Engaging minds: Changing teaching in complex times.* New York & London: Routledge.

Dehaene, S. (2007). A few steps towards a science of mental life. *Mind, Brain, and Education* 1(1): 28-47.

Dehaene, S. (2009). *Reading in the brain: The science and evolution of a human invention.* New York: Penguin Viking.

Edelman, G.M. (1987). *Neural Darwinism: The theory of neuronal group selection.* New York, NY: Basic Books.

Edelman, G.M. (1989). *The remembered present*. New York, NY: Basic Books.

Ericsson, K.A., K. Nandagopal & R.W. Roring (2009). An expert-performance approach to the study of giftedness. In L. Shavinina (ed.), *International handbook on giftedness*, 129–153. Berlin: Springer.

Fischer, K. W. (2009). Mind, brain, and education: Building a scientific groundwork for learning and teaching. *Mind, Brain, and Education* 3(1): 3-16.

Fischer, K.W., U. Goswami, J. Geake & the Task Force on the Future of Educational Neuroscience (2010). The Future of Educational Neuroscience. *Mind, Brain, and Education* 4(2): 68-80.

Freeman, J. (2006). Giftedness in the long term. *Journal for the Education of the Gifted* 29: 384-403.

Geake, J.G. (2009). *The brain at school: Educational neuroscience in the classroom.* Sydney: McGraw Hill & Open University Press.

Goswami, U. (2008). *Cognitive development: The learning brain.* Philadelphia: Psychology Press of Taylor and Francis.

Grandin, T. (2009). How does visual thinking work in the mind of a person with autism: A personal account. *Philosophical Transactions of the Royal Society* 364: 1437-1442.

Gribbin, J. (1994). *In the beginning: The birth of the living universe*. London: Penguin Books.

Haier, R.J. (2009). What does a smart brain look like? *Scientific American Mind* 20(6): 26-33.
Haier, R.J. & R.E. Jung (2008). Brain imaging studies of intelligence and creativity: What is the picture for education? *Roeper Review* 30(3): 171-180.
Haier, R.J., R.E. Jung, R.A. Yeo, K. Head & M.T. Alkire (2005). The neuroanatomy of general intelligence: Sex matters. *NeuroImage* 25(1): 320-327.
Hanushek, E.A. & L. Woessmann, L. (2010). Sample selectivity and the validity of international student achievement tests in economic research. NBER Working Paper No. w15867.
Happé, F. & P. Vital (2009). What aspects of autism predispose to talent. *Philosophical Transactions of the Royal Society, B* 364: 1351–1357.
Howard-Jones, P.A., (2008). Philosophical challenges for researchers at the interface between neuroscience and education. *Journal of Philosophy of Education* 42(3-4): 361-380.
Huitt, W. & J. Hummel (2003). Piaget's theory of cognitive development. *Educational Psychology Interactive*. Valdosta: Valdosta State University.
Kaufman, S. B. & R.J. Sternberg (2008). Conceptions of giftedness. In S.I. Pfeiffer (ed.), *Handbook of giftedness in children: Psycho-educational theory, research, and best practices*, 347–365. New York: Springer.
Kline, M. (1996). *Mathematical thought from ancient to modern times*. New York: Oxford University Press.
Lakoff, G., & Núñez, R.E. (2000). *Where mathematics comes from: How the embodied mind brings mathematics into being.* New York: Basic Books.
LeDoux, J.E. (1996). *The emotional brain: The mysterious underpinnings of emotional life.* New York: Touchstone.
Llinás, R. (2001). *I of the vortex: From neurons to self*. Cambridge: The MIT Press.
Margoliash, D. & H.C. Nusbaum (2009). Language: The perspective from organismal biology. *Trends in Cognitive Science* 13(12): 505–510.
Markram, H., T. Rinaldi & K. Markram (2007). The intense world syndrome -an alternative hypothesis for autism. *Frontiers in Neuroscience* 1: 77-96.
Morrison, K. (2010). Complexity theory, school leadership and management: Questions for theory and practice. *Educational Management Administration & Leadership* 38: 374-393.
Mottron, L., M. Dawson & I. Soulières (2009). What aspects of autism predispose to talent. *Philosophical Transactions of the Royal Society* 364: 1351-1357.
Mowat, E. & B. Davis (2010). Interpreting embodied mathematics using network theory: Implications for mathematics education. *Complicity: An International Journal of Complexity and Education* 7(1): 1-31.
O'Boyle, M.W. (2005). Some current findings on the brain characteristics of the math gifted adolescent. *International Education Journal* 6(20): 247-251.
OECD. (2003). *Assessing scientific, reading and mathematical literacy: A framework for PISA 2006*. Paris: OECD.
Piaget, J. (1928). *The child's conception of the world*. London: Routledge.
Postle, B.R. (2006). Working memory as an emergent property of the mind and brain. *Neuroscience* 139: 23–38.
Samuels, B.M. (2009). Can the differences between education and neuroscience be overcome by mind, brain, and education? *Mind, Brain, and Education* 3(1): 45-55.
Schnotz, W. & C. Kürschner (2007). A reconsideration of cognitive load theory. *Educational Psychology Review* 19: 469-508.

Snyder, A.W. & D.J. Mitchell (1999). Is integer arithmetic fundamental to mental processing?: The mind's secret arithmetic. *Proceedings of the Royal Society London* 266: 587-592.

Sporns, O. (2010). *Networks of the brain*. Cambridge, MA: MIT Press.

Squire, L.R. & E.R. Kandel (2008). *Memory: From mind to molecules*. Second edition. Greenwood Village: Roberts and Company.

Stamovlasis, D. & G. Tasparlis (2005). Cognitive variables in problem solving: A nonlinear approach. *International Journal of Science and Mathematics Education* 3: 7-32.

Sweller, J. (1988). Cognitive load during problem solving: effects on learning. *Cognitive Science* 12: 257-285.

Sweller, J. (2007). Evolutionary biology and educational psychology. In J.S. Carlson & J.R. Levin (eds.), *Educating the evolved mind: Conceptual foundations for an evolutionary educational psychology, Volume II of Psychological perspectives on contemporary educational issues*, 165-175. Charlotte: Information Age Publishing.

Tonegawa, S., K. Nakazawa & M.A. Wilson (2003). Genetic neuroscience of mammalian learning and memory. *Philosophical Transactions of the Royal Society of London, B* 358: 787-795.

Vialle, W. & K.B. Rogers (2009). *Educating the gifted learner*. Terrigal: David Barlow.

Woolcott, G. (2011). A broad view of education and teaching based in educational neuroscience. *International Journal for Cross-Disciplinary Subjects in Education, Special Issue* 1(1): 601-606.

Zhu, H-W. (2007). On the educational value of Mathematics Olympiad, *Journal of Mathematics Education*, 2. Retrieved http://en.cnki.com.cn/Article_en/CJFDTOTAL-SXYB200702003.htm [March 1 2001].

Ziegler, A. & S.N. Phillipson (2012). Towards a systemic theory of gifted education. *High Ability Studies* (in press).