HIGH-ABILITY LEARNING AND BRAIN PROCESSES:

HOW NEUROSCIENCE CAN HELP US TO UNDERSTAND HOW GIFTED AND TALENTED STUDENTS LEARN AND THE IMPLICATIONS FOR TEACHING

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ABSTRACT

Gifted and talented learners understand, think and know in ways that differ qualitatively from how regular learners perform these activities. Recent research that has examined the neuropsychological processes engaged by these learners provides insights into how they process information, convert it to knowledge and make links. It also assists in understanding the creative activity they display. These findings, in turn, assist in understanding how these students learn and think and how they can be taught.

This discussion reviews this research and links it with an explicit model of gifted and talented learning. The review helps teachers and schools understand what gifted and talented learning, in its multiple forms, 'looks like' or how it is displayed in regular classrooms. The discussion also identifies implications for identifying gifted and talented learning and for teaching these students. It focuses particularly on recommendations for implementing pedagogic and curriculum differentiation.

The phenomenon of giftedness is usually associated with high-level outcomes, whether on a measure of general ability, responses to achievement task, a performance or a production. The focus of this session is on the thinking and knowing that leads to these outcomes.

The context for this session is the classroom. Its perspective is the set of learning–teaching interactions that lead to the gifted outcomes. It is in these interactions that links with brain processing are more visible, as long as educators can recognise and interpret them.

This presentation begins by describing typical interpretations made by gifted students in a regular mathematics lesson. It unpacks these interpretations in terms of the learning and thinking processes that were implicated. It then links these outcomes with recent investigations of the neuropsychological processes associated with gifted learning. It concludes by examining implications for pedagogic and curriculum differentiation.

WHAT HIGH-ABILITY LEARNING LOOKS LIKE IN THE CLASSROOM: AN ANECDOTE

A Year 9 maths teacher introduces her students to Pythagoras, to the idea that the area of the square on one side of right-angled triangles (the hypotenuse) is equal to the addition of the area of the squares on the other two sides. They learn this as a formula, for example, $c^2 = a^2 + b^2$, and use it to calculate the length of the sides in triangles of this type.

This teacher asked: 'Did anyone think of ideas about this that I haven't mentioned?' Anna, without directed teaching, speculated about joined right-angled triangles in building construction, architecture and civil engineering, for example, in the triangular struts in girders holding up bridges. 'Are these triangles somehow stronger than squares or other types of triangles?', she asked. Con looked at curved surfaces in the classroom and wondered whether Pythagoras holds on curved, wavy or three-dimensional surfaces.

In another class, Gus reflected on the whole number triplets that are described by $c^2 = a^2 + b^2$ – for example, 3, 4 and 5, or 12, 5 and 13 – and wondered what the special pattern is between these numbers. He asked whether the tetruplet relationship $d^2 = a^2 + b^2 + c^2$ existed and whether there are sets of 4 whole numbers that satisfy it. He asked: 'What the sum of four squares would look like spatially?' Toni imagined a cube on each side of a right-angled triangle instead of squares and questioned whether $c^3 = a^3 + b^3$ would hold for some whole numbers and what this might look like spatially. She recalled rational numbers: 'Are the fractions that fit the pattern only those that comprise the whole number triplets or tetruplets?'

Other students learn Pythagoras very rapidly, after one or two examples only, and are ready to use it to solve more difficult tasks. Through guided dialogue and teaching, they extend their understanding of Pythagoras to more two- and three-dimensional word problems. They depend on the explicit teaching but can extend, apply or 'stretch' the taught understanding.

DESCRIBING THE UNDERSTANDING OF THESE STUDENTS IN REGULAR CLASSROOMS

To explain high-ability knowing and thinking, we need to focus on the specific 'meaning units' that comprise the knowledge of these students at any time. These units are linked in networks. When we detect information, some of our networks are 'lit up' or stimulated and we use them to comprehend the information, think about it and to respond to it.

Learning is about linking the meaning units in novel ways. This perspective helps us 'get inside students' heads' and speculate about how they make these links. It gives us tools for examining how students link the ideas they are learning at any time.

The gifted students above generated more elaborated and differentiated networks of meanings. Their class peers learnt essentially what the information taught; in right-angled triangles a particular relationship existed between the sides. They constructed meaning networks that represented this. They internalised the teaching information and formed an essentially literal understanding of it. Their links basically matched those in the information.

Anna, Gus and Toni formed an understanding that was more comprehensive than what was in the teaching information. They generated spontaneously interpretations about Pythagoras during the lesson that were more comprehensive.

The interpretations formed by the gifted students here comprised both links from the teaching and links they formed independently. They extended ideas in the taught understanding. They saw the taught ideas as parts of patterns and linked them with other aspects of what they knew. They inferred links and formed intuitions or suppositions that were unique to them, a phenomenon also noted by Robinson and Clinkenbeard (2008). The average learner may infer and extend spontaneously beyond the teaching but their inferences are usually lower level.

The gifted students' understanding was organised into a personal intuitive theory about Pythagoras. They inferred patterns from the information and then inferred a 'big idea' that synthesised the patterns. They could ask questions about their understanding and could generate ways of testing the new idea-links. They differed in the personal theories they formed. Their broader, more extensive, 'enlarged and enriched' meaning networks allowed them to understand the topic worlds in ways that differed qualitatively from that of their non-gifted peers.

THE TYPES OF NETWORKS FORMED BY HIGH-ABILITY LEARNERS

Gifted students can think in 'larger chunks' of knowledge at a time. They retain and 'keep track of' more knowledge in their short-term memories or thinking spaces for the domain or domains in which they are gifted (Hermelin & O'Connor, 1986).

They form a personal, intuitive 'semantic theory' understanding of a topic they are learning (Schwitzgebel, 1999). This understanding is organised in a 'big-picture' hierarchical way that has more the characteristics of an expert versus a novice understanding. They infer subjective patterns and personal rules for information and organise their meaning networks in a 'big picture' way that can be described as an 'expert +' understanding (Munro, 2013a).

Gifted students can interrogate, test and validate or modify their theories. They easily generate possibilities and questions for doing this. They add this new personal understanding to their existing knowledge. This becomes their more elaborated network of meanings for the topic.

On subsequent occasions they can search what they know more rapidly and more easily recognise situations in which the information doesn't match or clashes with what they know. They can 'see' problems, inquiries, uncertainty or inconsistencies in the links between the teaching information and what they know, and see how to frame up intellectual challenges, problems or questions.

High-ability students generate this understanding in part through their selective and spontaneous use of higher level, more complex thinking strategies that differ from those used by average students (Muir-Broaddus, 1995). They more ably manage and direct their thinking activity, set learning goals, plan, rehearse, monitor or self-check, focus and persist with difficult tasks (Alexander, 1996; Alexander, Carr & Schwanenflugel, 1995). When beginning an unfamiliar task, they know better why particular strategies work, use them more efficiently and learn new strategies more easily (Annevirta & Vauras, 2001; Schwanenflugel, Stevens & Carr, 1997). They often operate as 'intuitive philosophers' and form personal theories of intelligence (Hsueh, 1997).

MULTIPLE FORMS OF GIFTED KNOWING AND UNDERSTANDING

We have noted that there are multiple forms of gifted knowing and understanding. In terms of the domain specificity of giftedness, the meaning networks link ideas within domains: for example, verbal-abstract or experiential-imagery domains and across domains.

Some students have richer, more elaborated networks of imagery knowledge while others have richer, more elaborated abstract conceptual ways of knowing a topic.

Gifted students also differ in how they think. Some gifted students learn faster: Renzulli's (2005) 'school-house giftedness' and Sternberg's (2005) 'analytical intelligence'. They are very easily programmed by the teaching information; they internalise it and form the intended understanding much faster than their peers. Their understanding comprises the network of concepts that are coded in the information.

Gifted students can do this because their more elaborated and differentiated networks allow them to process the teaching information in larger chunks and deal with more information at a time. They don't wait to be programmed in a bit-by-bit way. They infer, see the big picture, select, link and organise the main and subordinate ideas in the intended ways.

They organise and reorganise the ideas that comprise their new understanding in more complex ways. They recognise and infer the main ideas in information more rapidly than their peers. They structure and fit together the ideas in their own ways and check their interpretations against the information. Before this checking, their initial interpretations are likely to be intuitive.

Other gifted learners are more 'self-programming'. They spontaneously form a broader understanding that 'goes beyond' the teaching: Renzulli's (2005) 'creative-productive giftedness' and Sternberg's (2005) 'creative intelligence'. They infer and make links with ideas they know that are not mentioned. Con and Gus made inferences about Pythagoras that extended the teaching into their personal intuitive theories.

One way in which they do this is by making analogies between topics that seem unrelated to others; they 'see' similarities that may seem superficially different. This 'far transfer' thinking, linking topics and ideas in lateral, novel unexpected ways (Carr & Alexander, 1996) includes 'fluid analogising' (Geake, 2007). It helps them solve problems in unusual or novel ways, use imagination and fantasy and show 'intellectual playfulness'. As noted, their understanding at this time is an intuitive theory about the topic that has not yet been validated. They may not be able to justify it logically at this time but they can interrogate and investigate it.

In summary, during a teaching episode, gifted learners differ in the extent of elaboration and differentiation of the meaning networks they form. They also differ in the quality of the links, amount of knowledge they can think about at once and extent of their inferences or extensions and syntheses. The understanding of non-gifted students is usually less elaborated or extensive and more closely linked with the teaching information.

There are several other ways in which the thinking of gifted students differs from their average-learning peers. These include their attitudes and dispositions towards particular topics and to themselves as learners and thinkers, their motivation orientation, the influence of cultures to which they belong on their thinking, their concept of being a learner and their self and social identities (for example, Munro, 2013a). Limited space does not permit their analysis here.

BRAIN STUDIES TELL MORE ABOUT GIFTED LEARNING

There is converging evidence that gifted learners differ from their non-gifted peers in the neurological processes that underpin their learning. This evidence needs to be interpreted against the backdrop of disagreement about definitions and acceptable criteria of giftedness, multiple ways of being gifted and the comparatively small number of studies that examine this issue.

A repeated finding is that gifted learners show brain stimulation patterns not typically engaged by non-gifted learners ability (Geake & Hansen, 2005; Jin, Kim, Park

& Lee, 2007; O'Boyle, 2008). These stimulation patterns include the bilateral activation of the prefrontal cortex, the parietal lobes, and the anterior cingulate. Bilateral activation of the prefrontal cortex contributes to the enhanced metacognitive activity and self-management of learning and thinking noted earlier, increased spatial attention and greater working memory capacity.

The bilateral stimulation patterns permit functional contributions to thinking from both sides of the brain at any time. The enhanced interhemispheric communication (via the corpus callosum, increased grey:white matter ratio and glia:neuron ratio) assists in coordinating and integrating information between the cerebral hemispheres. Bilateral activation of the prefrontal cortex is associated with enhanced information processing and attentional functions.

The gifted learners didn't differ from their average-learning peers by engaging additional or unique network components. Instead they showed greater activation across the frontal–parietal network; their activation patterns suggested stronger interconnections than the average learner's brain. A particular network includes the prefrontal cortex, the anterior cingulate and the posterior parietal cortex. A network within the prefrontal cortex, for example, is active during fluid reasoning tasks (Geake & Hansen, 2005). The findings suggest that the gifted students have more sophisticated cognitive schemas that they use during higher level cognitive tasks.

But gifted individuals don't always show increased brain activity during cognitive task processing. Their 'more efficient brains' need less overall cortical stimulation, particularly in the prefrontal areas, to complete particular tasks (Haier & Benbow, 1995). This is the 'neural efficiency hypothesis' and it has received some empirical support. Subsequent research has showed how brain activity shifts, depending on the task and the age of the individual (Jin et al., 2007; Lee et al., 2006; O'Boyle et al., 2005). Higher ability was associated with increased parietal activity and a corresponding decrease in prefrontal activity (Klingberg, Forssberg & Westerberg, 2002). The data show a shift to more parietal activity with older subjects and with those who performed better on the task.

This trend from higher prefrontal to parietal stimulation has also be shown to depend on age for gifted learners. During fluid reasoning tasks, for example, 12- to 15-year-olds showed higher prefrontal activity (O'Boyle, 2005) while participants who were 18 years old and older showed increased parietal activity and decreased prefrontal activity. This is consistent behaviourally with the gradual automatisation of metacognitive activity with familiarity with task types.

Winner (2000) identified the following trends displayed by gifted students:

- Those gifted in mathematics, arts and music show enhanced right-brain activity when compared with average students on tasks specific to the right hemisphere, greater right-hemisphere to left-hemisphere alpha activity (Alexander, O'Boyle & Benbow, 1996) and higher right-hemisphere activation than average peers on visuo-spatial construction tasks (Jin et al., 2007).
- Those gifted in mathematics and music show enhanced bilateral, symmetrical brain organisation where the right hemisphere appears to be more involved in tasks ordinarily reserved for the left hemisphere.
- Those gifted in spatial activities are more likely to show a higher incidence of language-related disorders, including dyslexia, than non-gifted peers (Craggs, Sanchez, Kibby, Gilger & Hynd, 2006).

The domain of giftedness that has attracted greatest neuropsychological research is mathematics, studied particularly by O'Boyle and colleagues. Their studies suggest that mathematically gifted students use cortical regions not typically used by their average-learning peers. One characteristic is the enhanced development of the right cerebral hemisphere with specialised visuo-spatial processing ability and a bilateralism that involves enhanced connectivity and integrative exchange of information between the hemispheres (O'Boyle & Hellige, 1989; Singh & O'Boyle, 2004). These learners display bilateral activation of the prefrontal cortex, the parietal lobes and the anterior cingulate. The latter regions form a neural circuit that mediates spatial attention and working memory and contributes metacognitive functions (Mesulam, 2000). They influence deductive reasoning and the development of cognitive expertise (Knauff, Mulack, Kassubek, Salih & Greenlee, 2002).

The origin of the differences in neurological processes has yet to be explained. One theory that has gained in popularity over the last decade relates to the influence of *in utero* factors during the second and third trimesters, when the rate of brain development is most rapid (Mrazik & Dombrowski, 2010). This is the 'prenatal testosterone model' proposed by Geschwind and Galaburda (1987) and later taken up by investigators of gifted learning (O'Boyle, 2008).

EDUCATIONAL IMPLICATIONS

Haier and Jung (2008) noted that, while understanding the neural basis for individual differences in general ability may be the most important challenge to educators in the next decade, its relevance has attracted little empirical attention. They also noted that 'even if neuroscience results offer educators potential advances, it is not clear that the education community is ready or prepared to listen' (Haier & Jung, 2008, p. 171). The discussion in this section is made from this perspective.

For gifted learners, educational implications include protocols for identifying instances of gifted knowing and strategies for differentiating the curriculum and pedagogy. Within the limitations and restrictions noted above, the neuropsychological data suggest that both identification and teaching provision take account of these aspects:

- students' enhanced metacognitive capacity to self-manage and direct their learning activity
- students' enhanced greater working memory capacity and the ability to process and manipulate a higher information load. This leads to a capacity to engage in higher level cognitive tasks.
- students' enhanced bilateral parietal activation and the capacity to integrate understanding from multiple codes. This includes pedagogy that scaffolds spatial and visual imagery.
- students' capacity to engage in far transfer and fluid analogy and to generate intuitive theories about topics they are learning.

Identification procedures can assess each of the aspects. Pedagogic provision can take account of them. Munro (2013b) explores these links explicitly.

An example of the potential interaction between cognitive-affective and neuropsychological studies of gifted understanding relates to the description of gifted understanding from the perspective of the 'expert knower' model. Cognitive analysis of the trend from a novice to an expert understanding of a topic identifies the critical role of metacognition (Bransford, Sherwood, Vye & Rieser, 1986). Research of gifted learning identifies this as a distinguishing feature. The review of the neuropsychological research shows the enhanced activity of the prefrontal cortex. What this approach also shows are the likely links made by the prefrontal with the parietal cortex, thus facilitating the likelihood of unusual or 'creative' outcomes. The bilateral activation matches the enhanced working memory capacity needed to achieve the 'expert+' understanding characteristic of gifted learners.

Linking the cognitive-affective and neuropsychological approaches has much to offer. It may, for example, allow gifted understanding to be described in terms of its 'quality', complexity and extent of differentiation. This could assist in resolving the current disagreements about what constitutes criteria for giftedness and the protocols used to identify it.

IN SUMMARY

Gifted students differ from their non-gifted peers' regular classroom learning-teaching interactions in their capacity to generate intuitive theories about the topics they learn. Their networks of meanings contain both links that are programmed by the teaching and links that are, at one time, more personal and intuitive. Studies of the neuropsychological processing of these students are consistent with this. Synthesised with psycho-educational research, they provide the opportunity for resolving current issues in our understanding of giftedness and efficacious educational provision.

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