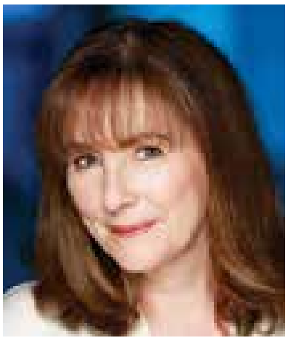
THE WOMAN WHO CHANGED HER BRAIN



BARBARA ARROWSMITH-YOUNG

Barbara Arrowsmith-Young is recognised as the creator of one of the first practical treatment applications using the principles of neuroplasticity. As the founder of the Arrowsmith Program, she began using these principles in 1978 to develop cognitive programs to deal with learning disorders, first starting with her own debilitating set of brain deficits. In her presentation she will talk about her journey of discovery, the lines of research she combined and the outcomes achieved over her 30-plus years as an educator and researcher. She will describe a number of learning disorders, from those that affect the learner in school to those that affect us in life. She will discuss 'cognitive glitches' – those areas of weakness that we are all familiar with and often explain away by saying, 'I am just not good at navigating/recognising faces/[fill in the blank]'. She will discuss 'cognitive mismatches' – situations we find ourselves in where the demand of the task is incompatible with our cognitive functioning and the challenges this presents. The nature of the transformation that occurs as the function of deficit areas are stimulated through cognitive exercises will be presented.

This talk will cover the personal and the universal. The personal is Arrowsmith-Young's journey of discovery driven by her hunt for a solution to her own debilitating learning disorders. The universal is that we all have a brain and, by furthering our knowledge of how our brain shapes us through mediating our understanding of the world, we can gain insight into our functioning and that of others. And, most promisingly, through our growing understanding of neuroplasticity, we now have the knowledge to develop treatments to shape our brains.

ABSTRACT

Neuroscience research can inform us in many ways. It can tell us about normal cognitive development: what regions of the brain and networks are critically involved in certain aspects of behaviour and learning. It can inform us about abnormal development: what regions are not functioning normally and those that could benefit from intervention with the goal of improving function in order to allow individuals to learn effectively. Through understanding the nature of various cognitive functions, we can create cognitive programs to stimulate and strengthen the functioning of these areas using the principles of neuroplasticity with the goal being to enhance functioning where it is needed to allow learning to proceed.

Neuroscience can provide knowledge about brain mechanisms and processes that can be used to enhance or improve learning. The application of this knowledge needs to be guided by careful research so that the practices are sound and of benefit to the learner.

This is an exciting time for educators and neuroscientists as we explore how to translate what we are learning into positive learning experiences. This knowledge has the potential to show us how we can change the capacity of the learner to learn.

The pursuit of developing neuroplasticity-based interventions for education and learning will benefit from – and best serve our students if there is – strong collaboration between researchers, educators, parents and the students themselves.

The concept of *neuroplasticity* or *brain plasticity* might feel new but that's because in the last few decades there has been a proliferation of mainstream writing taking neuroscience research findings out of the laboratory and into public awareness. In fact, research in neuroplasticity has been under way for more than 200 years. Santiago Ramón Y Cajal (1852–1934), one of the great pioneers in neuroscience, theorised the concept of neuroplasticity long before we had the refined technology and techniques to demonstrate it. Cajal knew, but could not prove, that the brain can be remapped, its very structure and organisation changed by the right stimulation.

'Consider the possibility', he once said, 'that any man could, if he were so inclined, be the sculptor of his own brain, and that even the least gifted may, like the poorest land that has been well cultivated and fertilized, produce an abundant harvest' (Cajal, 1999, p. xvi). This Spanish neuroscientist won the Nobel Prize in 1906. Almost a century later in 2000, Eric Kandel won the Nobel Prize for his work, which confirmed Cajal's hypothesis that the brain is plastic. Kandel demonstrated the growth of new synaptic connections as a result of learning in response to environmental demands.

Neuroplasticity, simply put, is the brain's ability to change structurally and functionally, in response to stimuli – to grow dendrites, to make new neural connections, to alter existing connections, to grow new neurons (neurogenesis). Neuroplasticity provides a mechanism through which we can fundamentally change the brain's capacity to learn and to function (Cramer et al., 2011; Kays, Hurley & Taber, 2012; Lillard & Erisir, 2011; Lövden, Backman, Lindenberger, Schaefer & Schmiedek, 2010).

Neuroplasticity as a process can lead to changes that affect functioning in either positive or negative ways.

> *When confronted with major changes or challenges, the brain can adapt by remodeling and refining existing connections. Communication pathways can be strengthened or enhanced by outgrowth of dendrites, axonal sprouting, and increasing or strengthening synaptic connections. Conversely, various factors can contribute to loss of synapses, shrinkage or retraction of dendrites (de-branching), and pruning of axons, thereby reducing communication in those areas. (Kays et al., 2012, p. 119)*

In order to harness neuroplasticity for practical applications, we need to understand what research has shown to be important factors in evoking these neural changes. We need to investigate how we can effectively reduce the factors leading to negative neural changes and increase the factors leading to positive neural changes.

Some of the factors leading to negative brain changes are chronic negative stress, prolonged anxiety, chronic pain and certain mental illnesses. Some of the factors leading to positive brain changes are active sustained engagement in the learning process, environmental enrichment, task demand or effortful processing or both, novelty and complexity, exercise and reward and performance feedback systems.

We know that there is variability in brain plasticity and research is looking at genetic factors that may play a role. Individual differences related to dopamine, a neurotransmitter that plays an important role in plasticity, are being investigated (Pieramico et al., 2012; Söderqvist et al., 2012).

We know that any learning process involves the brain – when we plan a trip, read a book, solve a maths or word problem, we are using our brain. However, not all learning experiences are equal in causing lasting and meaningful brain change. There are important questions to investigate:

- what is the difference between what happens in the brain in the normal course of using it and what happens as the result of very specific targeted experiences?
- what is the nature of the experience/learning/process/intervention required to lead to long-term functional

differences that affects the individual's ongoing and future learning and cognitive processing?

In a similar way that short-term anxiety or stress or acute pain lead to immediate changes in the brain, it is the long-term exposure to these conditions that leads to the significant long-term negative effects that Kays et al. (2012) noted. Lillard and Erisir (2011) speak to this:

> *Whether those changes are very temporary, involving mainly synaptic strength and temporary facilitation or inhibition, or entail longer term change in the numbers of synapses in a cortical field, has importance for how those connections will be used. If one wants only a temporary trick, it can be induced quickly; if one wants it to last, it must be induced gradually, allowing for harder neuroplastic change. (p. 231)*

> *Regardless of the source, a sustained change in a pattern of neural activity is a necessary trigger for neuroplasticity. The change in neural activity pattern leads to a reorganization in neural circuits, which produces long lasting functional change. Thus, the capacity of neural circuits to reorganize (neural malleability or neuroplasticity) enables the brain to use its internal resources more efficiently to respond to external information as a new repertoire of behaviors. (p. 208)*

Research is investigating the factors involved in harnessing neuroplasticity to enhance learning and to develop interventions to treat a range of disorders. A good review of this research is found in the article 'Harnessing neuroplasticity for clinical applications' (Cramer et al., 2011). Applications are being developed for rehabilitation after traumatic brain injury, improving cognitive functions impaired by various forms of mental illness, staving off cognitive decline accompanying the ageing process, general enhancement of cognitive functioning and for the treatment of various learning disorders.

Approaches to deal with dyslexia have been informed by neuroscience research. Imaging studies have found that the brains of dyslexics show different activation during reading tasks from the brains of proficient readers and that – after intensive remediation targeting phonological processing and, in some studies, both phonological and auditory processing – the children with dyslexia show increased activity in multiple brain areas, bringing brain activation in these regions closer to that seen in normal-reading children (Temple et al., 2003; Shaywitz et al., 2004; Meyler, Keller, Cherkassky, Gabrieli & Just, 2008). Studies demonstrate that children with dyslexia, through targeted training, can strengthen parts of the brain that enhance their ability to read. 'What we demonstrate is that we can change the way the brain works', says Marcel Just, director of the Center for Cognitive Brain Imaging at Carnegie Mellon (Meyler et al., 2008).

Neuroscience research has led to the development of programs designed with the intention of strengthening cognitive functions through stimulating neural processes to ultimately improve learning. Programs to tackle temporal acoustic processing – the ability of the brain to process rapidly presented speech sounds necessary for understanding speech and the acquisition of language, and which also plays a role in attaching sounds to symbols necessary for the reading process – have been shown to change regions of the brain related to the sound structure of language and to improve performance on measures of oral language ability and, in some studies, word blending, an aspect of phonological awareness (Merzenich, Jenkins, Johnston, Schreiner, Miller & Tallal, 1996; Temple et al., 2003; Heim, Keil, Choudhury, Friedman & Benasich, 2013).

Another program arising from research in the neuroscience laboratory is designed to deal with the construct of working memory – a term first used in the 1960s, referring to the capacity to hold and manipulate information in one's mind for brief periods of time (Pribram, Miller & Galanter, 1960; Baddeley, 2003). Working memory capacity has been found to be a strong predictor of future academic success (Alloway, 2009). Researchers have found that the ability to retain and manipulate information in working memory depends on a core neural circuit involving the frontal and parietal regions of the brain with other areas recruited as required depending on specific demands of the task: for example, verbal tasks will call on different regions from tasks that involve identifying objects (Rottschy et al., 2012). This same frontal–parietal network plays an important role in the control of attention and, as expected, working memory deficits are found in individuals with ADHD (Martinussen, Hayden, Hogg-Johnson & Tannock, 2005; Fassbender et al., 2011). Several studies have shown that working memory training leads to activation changes in the frontal–parietal network and improved performance on tasks requiring working memory and those involving attentional control (Klingberg et al., 2005; Klingberg, 2010) and that the gains in working memory were retained six months after the training (Holmes, Gathercole & Dunning, 2009; Holmes, Gathercole, Place, Dunning, Hilton & Elliott, 2010).

My work, begun in 1978, developed from two lines of research: research demonstrating neuroplasticity as a result of environmental enrichment (Rosenzweig) and research into the cognitive functions of regions of the brain (Luria).

The work of A. R. Luria (1966, 1970, 1972, 1973, 1977, 1980) established that different areas of the brain working together in a network are responsible for complex mental activities, such as reading or writing or numeracy. Each of these brain areas has a very specific and critical role to play in the learning process and a problem in the functioning of an area can affect a number of different learning processes.

In 1978 an article published in *Scientific American* confirmed, using brain imaging, that higher mental processes involve specific functional systems comprised of particular groups of brain areas working together (neural networks). This fact was confirmed by measuring the changes in blood flow to specific brain areas when a person was engaged in different tasks. An increase in blood flow directly relates to an increase in cortical activity. These researchers stated:

> *The analysis of cortical activation during reading illustrates that a complex task is carried out by several circumscribed cortical regions brought into action in a specific pattern … In general our results confirm a conclusion reached by the late A. R. Luria of Moscow State University on the basis of his neuropsychological analyses of patients with brain damage: 'Complex behavioral processes are in fact not localized but are distributed in the brain, and the contribution of each cortical zone to the entire functional system is very specific'. (Lassen, Ingvar & Skinhoj, 1978, p. 70)*

This led me to consider that a learning dysfunction might be the result of an area of the brain that is weaker in functioning than other areas in a network, thereby significantly impairing the learning activities of the network in which it is involved. Problems in learning and cognitive functioning can occur at many levels: in a brain area; in the connections between areas; and in the network.

The specific nature of the learning dysfunction depends upon the characteristic mental activities or operations of the particular area that is impaired and will be manifested in all the functional systems (neural networks) of which it is a component. For example, a problem in the area(s) responsible for motor planning in learning symbol sequences will affect learning motor plans in writing, reading, speaking and spelling.

Mark Rosenzweig (1966; Rosenzweig, Bennett & Diamond, 1972) investigated the effects of environmental enrichment on learning and the physiology of the brain, demonstrating neuroplasticity in rats. He found that the physiological changes in the brains of these rats were related to better learning: they performed better on maze tests. The conclusion: enriched stimulation led to physiological changes in the brain (neuroplasticity) that led to improvements in learning.

Luria's work led to the understanding and identification of the function of very specific cognitive areas critical to the learning process that became the basis of the Arrowsmith Program's cognitive exercises. Rosenzweig's contribution led to the idea that specific targeted cognitive programs might be able to exercise or stimulate and improve the functioning of these cognitive areas. In 1978, I created the first cognitive exercise to deal with my own severe learning problems and over time developed a range of cognitive exercises to tackle learning problems related to reasoning; thinking, planning and problem solving; visual memory for symbol patterns; lexical memory; memory for objects and faces; number sense and quantification; kinaesthetic perception; spatial reasoning; learning motor plans; and non-verbal thinking required for effective social interaction. I described this journey in my book, *The woman who changed her brain* (2012).

WHAT DO PROGRAMS DESIGNED TO TRAIN COGNITIVE FUNCTIONS HAVE IN COMMON?

UNDERLYING PRINCIPLES TO EVOKE NEUROPLASTIC CHANGE

The principles built into the program I began to create in 1978 are those that research now indicates are important factors to evoke positive brain change:

- design a task that places demands on a specific cognitive function (targeted/differential stimulation)
- start the level of task difficulty just above the level of current functioning and, as the individual attains mastery at that level, incrementally increase the difficulty (effortful processing; complexity; cognitive load)
- remove the support, wherever possible, of any areas that could compensate for the targeted weaker area of functioning (targeted/differential stimulation; effortful processing; novelty)
- build in performance mastery criteria that is rewarded (sustained attention; active engagement; reward effects on dopamine)
- repeated and prolonged practice.

Adele Diamond (2012) summed this up as 'hours and hours of practice trying to master what is just beyond your current level of competence and comfort (working in what Vygotsky, 1978, would call the "zone of proximal development")' (p. 337). This is Hebb's principle – neurons that fire together wire together – and the more they fire together, the stronger the connections (Sejnowski & Tesauro, 1989). 'If a network supporting a brain function is repeatedly stimulated through practice and training, it will become stronger, contributing to the optimization of that brain function' (Fernandez, 2013, p. 20).

GOAL OF COGNITIVE PROGRAMS

The goal of a cognitive program is not to teach content or the acquisition of skills. The goal is to change the underlying cognitive functions that are the basis of a wide range of learning processes that then allow for the learning of content and acquisition of skills. The premise of these cognitive programs is grounded in the principles of neuroplasticity – that the learner is not fixed, that the learner's brain is capable of meaningful and positive change – so that we do not have to compensate or work around cognitive problems but so that we can fundamentally change the learner's capacity to learn by creating cognitive programs that apply the principles listed above to evoke positive neuroplastic change.

TRANSFER: PROGRAM EFFECTS MUST TRANSLATE INTO REAL-WORLD CHANGE

A measure of the effectiveness of these programs is whether the change transfers to other areas of learning. For any of these changes to be meaningful, change must show up not just in brain-imaging studies or on better performance on the cognitive exercise, but critically as cognitive or behavioural change in the individual's real-world functioning.

Schmiedek, Lövden and Lindenberger made this point:

> *[the goal of these programs must be] the improvement of abilities, denoting gains in general mechanisms and capacities that carry the potential for improved performance across a wide range of tasks (cf. Thorndike, 1906). If training does not just improve task-specific skills but also broad cognitive abilities (cf. Carroll, 1993), then even small effects could lead to important benefits for individuals' everyday intellectual competence, as these improvements would generalize to all sorts of cognitive activities. (2010, p. 1)*

Given the complexity of the brain and its networks, we need to find multiple ways to measure these changes using behavioural observations from multiple sources (students, teachers, parents) to measure observable changes in real world functioning; measures of cognitive performance related to the functions being worked on; changes in rate of learning and acquisition of skills; changes in academic performance; longitudinal follow-up measures tracking academic, social and vocational progress; and brain imaging. A cautionary note has emerged from the research: brain change can take time to translate into measurable change on standardised academic test measures. This is probably explained by the fact that, once the cognitive capacity is in place, for academic skill acquisition to occur the student needs to be exposed to the material to now learn it and to fill in the learning gap that is present given the previous learning problems. Over time, this gap is closed as the student acquires the academic skills with the new learning capacities.

SUSTAINED CHANGE OVER TIME

Change in functioning seen at the end of a cognitive program must also be measured longitudinally – one, two, three and more years after the end of the program – to ensure the change in functioning is sustained and not just practice effect or the short-term temporary wiring changes noted by Lillard and Erisir (2011).

ARROWSMITH PROGRAM OUTCOME STUDIES

There have been a number of outcome studies conducted on students undergoing the Arrowsmith Program set of cognitive exercises. Each student is on his or her own program of cognitive exercises based on his or her profile of cognitive strengths and weaknesses as determined through an initial assessment process. Progress is measured monthly based on attaining benchmark goals in each of the cognitive programs and progress is measured annually through an assessment. The program is modified based on the student's measured improvement, with exercises being removed once certain criteria are met and other exercises being added as required, again based on the assessment.

There is a document, 'Academic skills and learning outcomes' (Arrowsmith Program, 2012), that summarises these studies; the studies are on the Arrowsmith Program website and a list appears at the end of this paper. These studies were conducted from 1997 to 2007, used different research designs and different measures, were both educational and cognitive, studied students at different schools and all showed positive learning outcomes. The Lancee (2005) study found a specificity of effect: improvement on a specific cognitive program showed related improvement on standardised tests that loaded on those cognitive functions.

NEXT STEPS IN RESEARCH

The next step, for Arrowsmith Program, is to partner with neuroscience researchers to start to explore what is happening in the brain as a result of the different cognitive exercises. Discussions have begun with researchers at several universities and our goal is to be underway designing this research in the next year.

NEUROEDUCATION – VISION FOR EDUCATION

Rather than change the way we teach, what is needed is to include cognitive programs as part of the curriculum so that students spend part of the day training their brains – the very organ they use to learn the curriculum and that they need when learning how to learn. Education becomes neuroeducation – the perfect marriage between neuroscience and education – and it will be about changing the capacity of the learner to learn as they learn. Through this partnership, the capacity to learn becomes as important as what is being taught.

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Arrowsmith Program Outcome Studies

These studies can be viewed here:

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