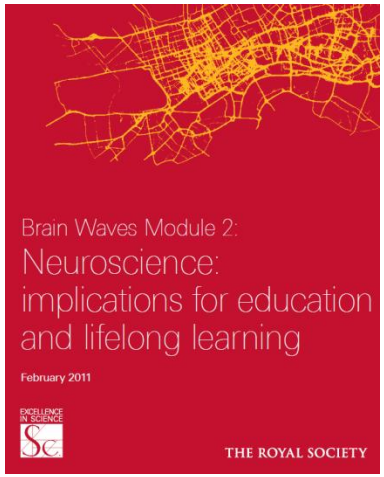
The Learning Brain

Dr Guy Sutton
Director, Medical Biology Interactive &
Honorary (Consultant) Assistant Professor,
University of Nottingham Medical School

To Be Addressed

- Neuromyths
- Brain Circuits, Cognition & Memory
- Sleep, Stress, Drugs & The Brain
- Genes, Environment & The Learning Brain
- Neuroplasticity & Development Across The Lifespan



"Education is far more than learning facts and skills such as reading. It is not confined to school years, but plays an important role throughout the lifespan and helps individuals cope with adversity. Flexibility through learning enables people of any age to adapt to challenges of economic upheaval, ill health, and ageing."

Frith, U. *et al* (2011). *Brain Waves Module 2: Neuroscience: implications for education and lifelong learning*. The Royal Society. p1.

Neuroscience & Education

In the past decade, there have been various attempts to apply knowledge of brain function to the field of education - including reading, learning, language and mathematics.

These new educational practices range from good to bad to insane!

Della Salla, S., Anderson, M. (2012). *Neuroscience In Education: The Good, The Bad, and The Ugly*. Oxford University Press.

"Imagine having a brain that is only 10% active, that shrinks when you drink less than 6 to 8 glasses of water a day and that increases its interhemispheric connectivity when you rub two invisible buttons on your chest. For neuroscientists, such a brain is difficult - if not impossible - to contemplate, but such notions are commonly held by teachers across the world."

Howard-Jones, P.A. (2014). Neuroscience and education: myths and messages. *Nature Reviews Neuroscience*. 15: 817–824.

Brain Myth	Percentage of teachers who "agree" rather than "disagree" or "don't know"				
	UK	N	G	T	C
We only use 10% of our brain	48	46	50	43	59
Individuals learn better when they receive information in their preferred learning style, e.g., visual, auditory, kinaesthetic	93	96	97	96	97
Short bouts of co-ordination exercises can improve integration of left and right hemispheric brain function.	88	82	72	60	84
Differences in hemispheric dominance (left brain or right brain) can help to explain individual differences amongst learners.	91	86	79	74	71
Children are less attentive after sugary drinks or snacks.	57	55	44	46	62
Drinking less than 6 to 8 glasses of water a day can cause the brain to shrink	29	16	25	11	5

Dekker *et al* (2012); Deligiannidi, K. & Howard-Jones, P. (2014), reported in: Howard-Jones, P.A. (2014). Neuroscience and education: myths and messages. *Nature Reviews Neuroscience*. 15: 817–824.

Brain Gym
Or Educational Kinesiology…Hmmm!

Rub either side of your breast bone in a special Brain Gym way called Brain Buttons: "This exercise stimulates the flow of oxygen-carrying blood through the carotid arteries to the brain to awaken it and increase concentration and relaxation. Brain buttons lie directly over and stimulate the carotid arteries."

Through your ribcage.
Without using scissors.

Goldacre, B. (2008). Bacscience.net

How Neuroscience is Affecting Education:
Report of Teacher & Parent Surveys

January 2014

Table Showing Teacher Responses To Schoolzone and Wellcome Trust Surveys

What impact have different methods or techniques had on students' academic performance?

	Learning styles	Brain Gym®	Left/right brain	Biofeedback
A significant impact	26% (209)	4% (20)	9% (21)	13% (2)
Some impact but difficult to measure	51% (413)	43% (202)	45% (110)	33% (5)
Not sure	14% (113)	28% (13)	35% (86)	33% (5)
No impact on academic performance but other benefits noted	6% (49)	18% (86)	5% (11)	0
No discernible impact	2% (20)	6% (29)	6% (15)	20% (3)
Total respondents	804	435	240	15

Cultural Factors & Beliefs About The Brain

"In the UK, where half of the population report no affiliation with any religion, only 15% of trainee teachers believed that the mind results from the spirit or the soul acting on the brain. By contrast, in Greece - which stands out among European states in terms of how religious its people are - 72% of trainee teachers believed in this idea."

Howard-Jones, P.A. (2014). Neuroscience and education: myths and messages. *Nature Reviews Neuroscience*. 15: 817–824.

The Power of Neuroscience Jargon!

Even irrelevant neuroscience information in an explanation of a psychological phenomenon may interfere with people's abilities to critically consider the underlying logic of this explanation.

Something about seeing neuroscience information may encourage people to believe they have received a scientific explanation when they have not.

Weisberg, D.S. *et al* (2008). The The Seductive Allure of Neuroscience Explanations. *Journal of Cognitive Neuroscience,* 20(3): 470–47.

The Brain & Learning

1) Cognitive functions
and neural pathways

2) The neurobiological
basis of memory formation

3) The neurobiological
consequences of stress
and drugs for learning

"The brain is an intrinsically multi-scale, multi-level organ operating across spatial scales ranging from nanometres (proteins) to metres (the human body) and temporal scales from picoseconds (atomic interactions) to years (the lifespan of a human being)."

Frackowiak, R., Markram, H. (2015). The future of human cerebral cartography: a novel approach. *Philosophical Transactions of The Royal Society B*, 370: 20140171

The Glass Brain

The structure of the brain is mapped using MRI.

EEG then records brain activity.

This activity is revealed on screen. Different colours represent the different frequencies of electrical activity in the brain, as well as the neural pathways.

http://neuroscapelab.com/projects/glass-brain/

Brain system behind general intelligence

General intelligence (Spearman' g-factor) seemingly draws on connections between regions that integrate verbal, visuospatial, working memory, and executive processes, in line with the 'parieto-frontal integration theory'.

These regions included white matter association tracts and frontopolar cortex

Gläscher, J. *et al* (2010). The distributed neural system for general intelligence revealed by lesion mapping. *Proceedings of the National Academy of Sciences*, 107(10):4705–4709.

Switching On One-Shot Learning

In this study, uncertainty in terms of the causal relationship - whether an outcome is actually caused by a particular stimulus - is the main factor in determining whether or not rapid learning occurs.

The ventrolateral prefrontal cortex (VLPFC) is involved in the processing and then couples with the hippocampus to switch on one-shot learning, as needed.

Wan Lee, S , O'Doherty, J.P., Shimojo, S. (2015). Neural Computations Mediating One-Shot Learning in the Human Brain. *PLOS Biology*, 13 (4): e1002137 DOI: 10.1371/journal.pbio.1002137

Granger, R.J., Nicoll, R.A. (2014). Expression mechanisms underlying long-term potentiation: a post-synaptic view, 10 years on. *Philosophical Transactions of The Royal Society B,* 369: 20130136.

To Sleep, Perchance To Clean

The restorative nature of sleep appears to be the result of the active clearance of the by-products of neural activity that accumulate during wakefulness.

Further, during sleep the brain's cells reduce in size, allowing waste to be removed more effectively.

Xie, L. *et al* (2013). Sleep Drives Metabolite Clearance from the Adult Brain. *Science*, 342:373-377.

Stress Interferes With Working Memory

The prefrontal cortex is required for executive functions such as planning and working memory. High activity of intracellular signalling enzyme, *protein kinase C* (PKC), disrupts ability to remember.

Stress causes release of *noradrenaline*, which in turn activates PKC.

Birnbaum, S.G. *et al* (2004). Protein kinase C overactivity impairs prefrontal cortical regulation of working memory. *Science*, 306: 882-884.

Short-term Stress Can Affect Learning & Memory

Short-term stress lasting as little as a few hours can impair brain-cell communication in areas associated with learning and memory.

Rather than involving cortisol, acute stress activates corticotropin releasing hormone, which leads to the rapid disintegration of parts of the nerve cell involved in memory formation.

Chen, Y. *et al* (2008). Rapid Loss of Dendritic Spines After Stress Involves Derangement of Spine Dynamics by Corticotropin-Releasing Hormone. *The Journal of Neuroscience*, 28(11):2903-2911.

‘Skunk’ & The Corpus Callosum

Smoking high potency 'skunk-like' cannabis can damage the corpus callosum, responsible for communication between the hemispheres

The corpus callosum is particularly rich in cannabinoid receptors, on which the THC content of cannabis acts.

Rigucci, S. *et al* (2016). Effect of high-potency cannabis on corpus callosum microstructure. *Psychological Medicine*, 46(4): 841-854.

Other areas of neurobiological study

1) The brain basis of reward, uncertainty and expectation in learning

2) The neurobiology of specific learning difficulties, such as developmental dyslexia and developmental dyscalculia (Goswami, 2008)

3) Adaptive learning technologies and digital educational systems

Genes, Environment & The Learning Brain

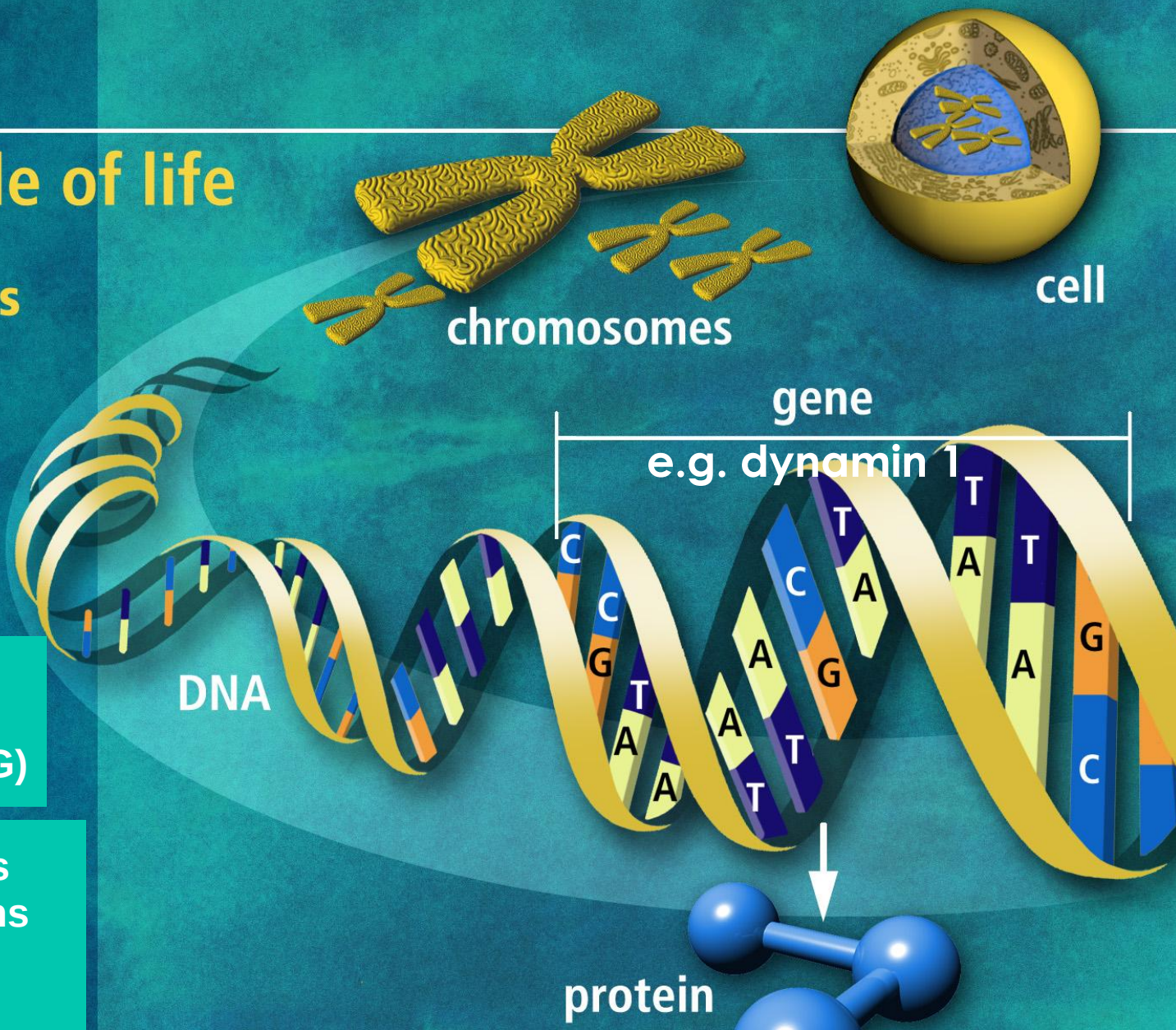
DNA

the molecule of life

Trillions of cells

Each cell:

- 46 human chromosomes
- 2 m of DNA
- 3 billion DNA subunits (the bases: A, T, C, G)
- 19,000ish genes code for proteins that perform all life functions



Ferguson, S.M *et al* (2007). A Selective Activity-Dependent Requirement for Dynamin 1 in Synaptic Vesicle Endocytosis. *Science,* 10: 40−68.

Y-GA 98-090R

3D Model of a Synapse

Nerve terminals are about one 1000/mm in diameter, and the space between them and the membrane they contact a mere 20-40 millionths/mm wide

Wilhelm, B. G. *et al* (2014). Composition of isolated synaptic boutons reveals the amounts of vesicle trafficking proteins. *Science*, 344: 1023-1028.

The Synaptic Vesicle

Synaptic vesicles are too small and fragile to capture and image with this level of detail. Takamori *et al.* (2006) used computer modeling to characterize what a synaptic vesicle would look like in three dimensions, based on what is known about more than 80 proteins embedded in the surface of these vesicles.

Takamori, S. *et al*. (2006). Molecular anatomy of a trafficking organelle. *Cell*, 127: 831-846.

Genes Driving Math & Reading Ability

Around half of the genes that influence how well a child can read also play a role in their mathematics ability, indicating a complex, shared genetic basis of these cognitive traits.

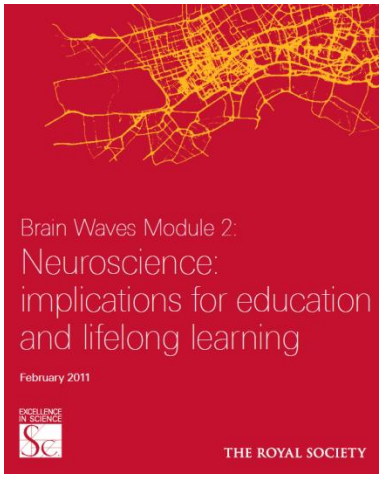
This does not mean that there is nothing we can do if a child finds learning difficult, it just means it may take more effort from parents, schools and teachers to bring the child up to speed.

Davis, O.S.P. *et al* (2014). The correlation between reading and mathematics ability at age twelve has a substantial genetic component. *Nature Communications* 5, doi:10.1038/ncomms5204

Genes influence academic ability across all subjects

Performance differences for all subjects are highly heritable at the end of GCSE study and that many of the same genes affect different subjects, independent of intelligence.

Rimfeld, K., Kovas, Y., Dale, P.S., Plomin, R. (2015). Pleiotropy across academic subjects at the end of compulsory education. *Scientific Reports*, 5: 11713



"It is a mistake to regard biological predispositions as deterministic; their impact is probabilistic and context-dependent."

Frith, U. *et al* (2011). *Brain Waves Module 2: Neuroscience: implications for education and lifelong learning*. The Royal Society. p17.

Different Teaching Methods Affect Brain Regions & Reading Development

Beginning readers who focus on letter-sound phonics (C-A-T) rather than whole words increased activity in brain regions optimised for reading.

Words learned through letter-sound instruction elicited LH bias – a hallmark of skilled readers; whole word association was associated with RH bias.

Yonchevaa, Y.N., Wiseb, J., McCandliss, B. (2015). Hemispheric specialization for visual words is shaped by attention to sublexical units during initial learning. *Brain & Language*, 169(3), 211-219.

Epigenetics & The Brain

Enhanced executive brain function and musical training

Adult musicians and musically trained children showed enhanced performance on aspects of executive functioning.

On fMRI, during a test that made them switch between mental tasks, the children with musical training showed enhanced activation of specific prefrontal cortex areas linked to executive function.

Zuk, J. *et al* (2014). Behavioral and Neural Correlates of Executive Functioning in Musicians and Non-Musicians. *PLoS ONE*; 9 (6): e99868 DOI: 10.1371/journal.pone.0099868

Neuroplasticity

the capacity of the nervous system to modify its organisation.

Synaptogenesis & Pruning

- Synaptogenesis results in a surplus of synapses in the prenatal brain, thus these connections undergo 'pruning', a form of neural 'fine tuning'.

- Histological studies of prefrontal cortex have shown a proliferation of synapses during childhood and again at puberty, followed by a plateau phase and subsequent elimination and reorganisation of prefrontal synaptic connections after puberty.

Switching between languages pays off

Bilingual children are better than monolinguals at a certain type of mental control, and those children with more practice switching between languages have even greater cognitive skills.

Bilinguals show strengthened cognitive flexibility and selective attention abilities as they have increased experience in switching across languages in expressive vocabulary.

Crivello, C. *et al* (2016). The effects of bilingual growth on toddlers' executive function. *Journal of Experimental Child Psychology*, 141: 121.

Bilingual baby brains show increased activity in executive function regions

Bilingualism-related difference in brain activity is evident as early as 11 months of age, just as babies are on the verge of producing their first words.

Ramírez, N. F. *et al* (2016). Speech discrimination in 11-month-old bilingual and monolingual infants: a magnetoencephalography study. *Developmental Science*, DOI: 10.1111/desc.12427

Effects of Neglect on Brain Development

Neglect in early life was associated with alterations in white matter microstructure throughout the brain, involving structures such as the corpus callosum and fornix.

Removal from conditions of neglect and entry into a high-quality foster care can support more normative trajectories of white matter growth.

Bick, J. *et al* (2015). Effect of early institutionalization on long-term white matter development: a randomized clinical trial. *JAMA Pediatrics*, 169(3):211-219.

Emotion versus Control

Development of the limbic system increases as puberty begins (years 10-12) maturing over several years. The prefrontal cortex does not approach full development until a decade later.

Greater Networking Brings Maturity

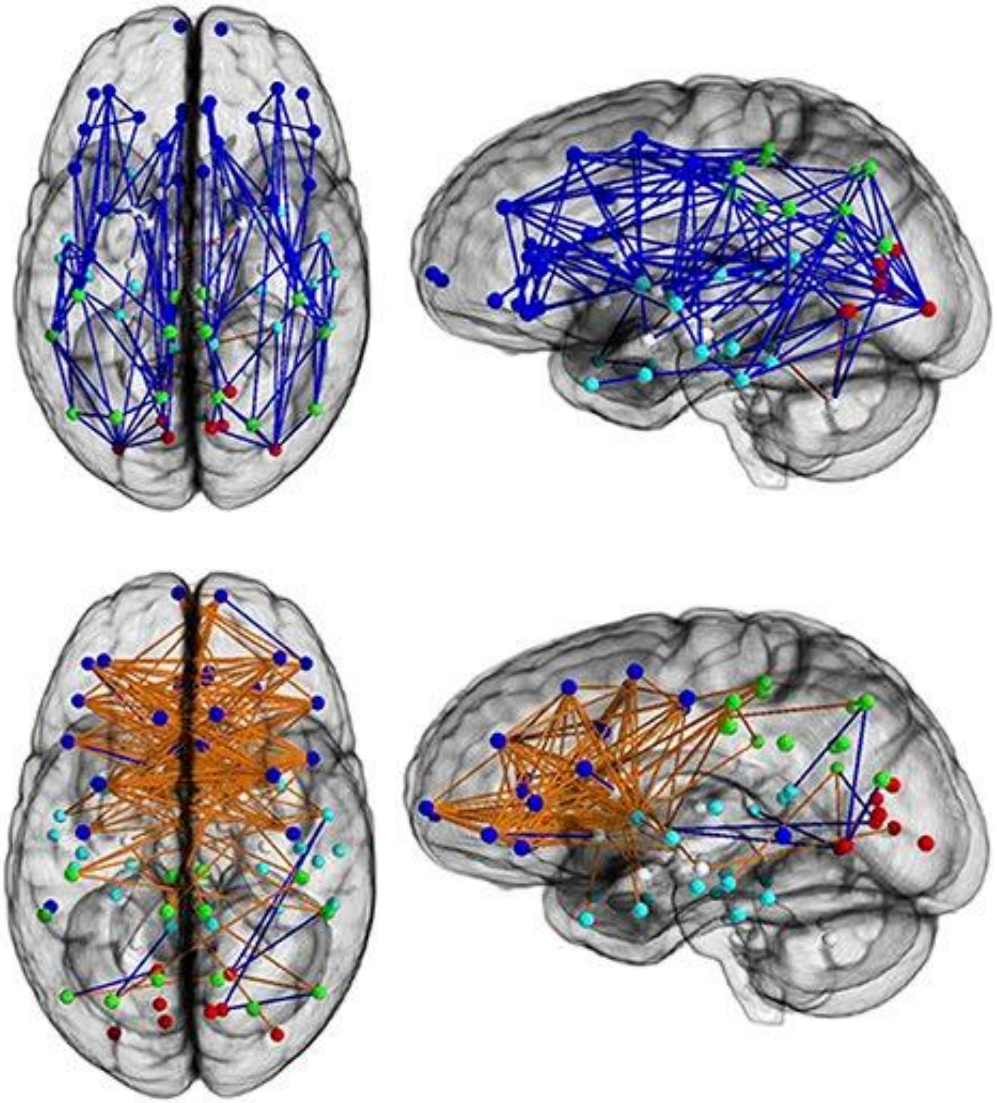
The most significant change in the adolescent brain is not the growth of brain regions but the increase in communication among groups of neurons, helping the brain to specialise in everything from complex thinking to social communication.

Dennis, E.L. *et al* (2013). Development of Brain Structural Connectivity between Ages 12 and 30: A 4-Tesla Diffusion Imaging Study in 439 Adolescents and Adults. *Neuroimage*; 64: 671–684.

"Just because you have a classroom full of students who are about the same age doesn't mean they are equally ready to learn a particular topic, concept, skill, or idea. It is important for teachers and parents to understand that maturation of the brain influences learning readiness. For teachers, this is especially important when designing lessons and selecting which strategies to use."

Margaret Semrud-Clikeman. (2016). *Research in Brain Function and Learning*. American Psychological Association.

Are Male & Female Brains Wired Differently?



Ingalhalikar, M. *et al* (2013). Sex differences in the structural connectome of the human brain. . *Proceedings of the National Academy of Sciences*, 111(2): 823–

Sex-specific changes in cerebral blood flow begin at puberty

Cerebral blood flow levels decreased similarly in males and females before puberty.

But levels then diverge sharply during puberty, with levels increasing in females while decreasing further in males.

This may provide hints as to developing sex differences in learning and sex-specific pre-dispositions to certain psychiatric disorders.

Satterthwaite, T.D. *et al* (2014). Impact of puberty on the evolution of cerebral perfusion during adolescence. *Proceedings of the National Academy of Sciences,* 111(23): 8643–8648.

Connectivity in human foetal brain networks

In utero whole-brain resting-state correlation maps corresponding to varied seed locations. Images are organized into columns corresponding to foetal age groups. Seed regions are shown in the first column on the left. Age-group 1-sample t-tests at $p < 0.01$ significance threshold are shown on representative coronal, sagittal, and axial slices overlaid on a 32-week foetal template.
Abbreviations: posterior cingulate cortex, PCC; anterior cingulate cortex, ACC; medial prefrontal cortex, MPFC; lateral prefrontal cortex, LPFC; superior temporal gyrus, STG.

Thomason, M.E. *et al* (2015). Age-related increases in long-range connectivity in fetal functional neural connectivity networks in utero. *Developmental Cognitive Neuroscience,* 11, 96–104.

Developing Human Connectome Project

The dHCP will deliver:

- the first dynamic map of human brain connectivity from 20 to 44 weeks post-conceptional age, linked to imaging, clinical, behavioural and genetic information;
- comparative maps of the cerebral connectivity associated with neurodevelopmental abnormality

Plasticity and the Hippocampus

Maguire *et al* (2006) found increased gray matter volume in the mid-posterior hippocampus, an area associated with spatial memory, in London black cab drivers.

Woollett, K., Spiers, H.J., Maguire, E.A.(2009). Talent in the taxi: a model system for exploring expertise. *Philosophical Transactions of The Royal Society B,* DOI: 10.1098/rstb.2008.0288 .

Experience-Dependent Structural Plasticity

In academic mathematicians, cortical gray matter density in the left inferior frontal lobe and bilateral inferior parietal lobules were significantly increased relative to controls.

Aydin, K. *et al* (2007). Increased gray matter density in the parietal cortex of mathematicians: a voxel-based morphometry study. *American Journal of Neuroradiology*, 28: 1859-1864.

Effects of cognitive training on the cognitive functioning of older adults

Older adults with less than 12 years of schooling benefit more from cognitive training than their more highly educated counterparts.

Such experienced a 50% greater effect from speed of information processing training than college graduates, and this effect was maintained for 3 years.

Clark, D.O. *et al* (2015). Does targeted cognitive training reduce educational disparities in cognitive function among cognitively normal older adults? *International Journal of Geriatric Psychiatry*, DOI: 10.1002/gps.4395

Challenges

- The charges of reductionism and determinism
- The inappropriate exploitation of neuroscience
- Building a common language

Educational Interventions

Mathematics
Reading
Exercise
Sleep, nutrition and hydration
Genetics
Embodied cognition
“Brain training” of executive function
Spaced learning

Interleaving
Testing
Learning games
Creativity
Personalisation
Neurofeedback
Transcranial electric stimulation (TES)

Howard-Jones, P. (2014). Neuroscience and Education: A Review of Educational Interventions and Approaches Informed by Neuroscience. Education Endowment Foundation. https://v1.educationendowmentfoundation.org.uk/uploads/pdf/NSED_LitReview_Final.pdf

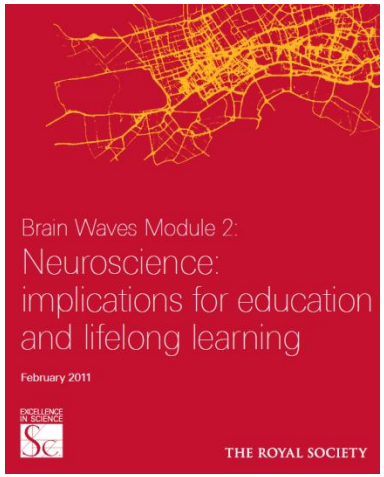
Conclusions

"Thirty years ago medicine wasn't particularly evidence-based. I think education is fundamentally not based on evidence. What programme has been rolled out that has been based on evidence? We ought to hold educationalists to the same standards of evidence as medicine." "

Professor Robert Plomin, Quoted in 'Genes influence academic ability across all subjects, latest study shows', The Guardian, Thursday 23 July 2015.

"Education needs to be treated like health, and the outcomes of new teaching strategies should be tested and evaluated before implementation in classrooms. We are in exciting times for neuroscience, where the merger of neuroscience with education takes us from the molecular and cellular understanding of brain function to the classroom."

Professor Pankaj Sah, Editor-in-Chief of NPJ Science of Learning



"Education is the most powerful and successful cognitive enhancer of all."

Frith, U. *et al* (2011). *Brain Waves Module 2: Neuroscience: implications for education and lifelong learning*. The Royal Society.

guy.sutton@nottingham.ac.uk