Using educational neuroscience and psychology to teach science.

Part 2: a case study review of the 'Brain-Targeted Teaching Model', and 'Research-based Strategies to Ignite Student Learning'.

This article is the second of a two-part series which explores science teachers' and their pupils' experiences of using different pedagogical approaches based on understandings of how brains learn (see footnote). [1] *Part one (Torrance Jenkins 2017) focused on the two approaches rooted in cognitive psychology: Cognitive Load Theory (CLT) and Cognitive Acceleration through Science Education (CASE).*
After an introduction to the field of educational neuroscience, Part two will explore experiences of using two teaching resources from educational neuroscience: 'The Brain-Targeted Teaching Model' (Hardiman, 2012) and 'Research-Based Strategies to Ignite Student Learning' (Willis 2006). Both approaches were selected for the case study research due to the strength of their scientific integrity, reliability and relatively substantial (and ongoing) empirical evidence.

Introduction.

We are living in the "*century of neuroscience*" (Goswami 2006:2) and the potential benefit that neuroscience has to offer education is vast: it has evolved from the early view that educational pedagogy is "*a foreign field to cognitive neuroscience*" (ibid.) to the belief that "*educational practice can be transformed by science, just as medical practice was transformed by science*" (Royal Society, 2011:v) and that understanding "*the brain mechanisms that underlie learning and teaching could transform educational strategies*" (Blakemore & Frith 2005:459). These are exciting times to be a teacher, and in particular to be a science teacher; it is standard practice for biology, chemistry and physics teaching to incorporate many of the multi-modal teaching methods proposed by both

[1] For this case-study research, which was part of a PhD study (Torrance Jenkins 2014), four science teachers, Emma, Sam, George and William, self-selected to trial a pedagogical approach new to them, from cognitive psychology and educational neuroscience for between one and two academic years. Data was collected via observations, interviews with teachers and focus-group interviews/written questionnaires with pupils. Each of the participant teachers undertook several cycles of action research, where the findings from each cycle fed into the next, and informed any proposed changes to teaching. As in case study research, each case was examined in depth, and consequently findings are not necessarily generalizable to other cases.

cognitive psychology and educational neuroscience, such as practical work, collaboration and trial-and error.

Encouragingly, findings from neuroscience have provided neurobiological evidence, and thus support, for some of the more long-standing cognitive psychology theories historically used in education and to inform pedagogy. Key to this has been the development of functional magnetic resonance imaging (fMRI) which allows us to see the brain whilst working rather than just its structure, and has "*enabled cognitive sciences to look into the black box (that is, the brain) to investigate what have been up until recently, merely theories that fit patterns of behaviour*" (Fadel & Lemke 2008:12). For example, brain plasticity – the brain's ability to make new connections between nerve cell dendrites following an experience – offers support for the concept of 'growth mindsets' and that intelligence is not fixed but can be modified: "*findings in neuroscience and cognitive psychology revealed the great plasticity of the brain and the fact that basic aspects of intelligence can be taught*" (Dweck 2008:15). Neuroscience is also "*confirming earlier psychological theories about the importance of emotional engagement in learning*" (Hall 2005:25).

What is educational neuroscience?

The field of educational neuroscience is still in its infancy. Broadly speaking, however, as "*education is about enhancing learning, and neuroscience is about understanding the mental processes involved in learning*" (Royal Society, 2011:v), there is an obvious collaboration to be made with the shared aim of improving pedagogy and learning. In practice, the field of educational neuroscience has emerged as a complex multidisciplinary collaboration between neuroscientists, cognitive psychologists, anatomists, educationalists and physiologists who are now sharing research findings on mental processes and brain structures. Neuroscience regards learning as a process that "*broadly comprises changes in connectivity*" (Goswami 2004:1) of some of the 100 billion nerve cells in the brain, and examines these processes at the molecular and cellular levels to see how neurons form cognitive systems, such as those which play their part in enabling us to speak, or read. Non-invasive neuroimaging methods (such as fMRI) are now able to determine which areas of the brain are related to learning, and "*how their neural correlates change*" (Hardiman et al. 2011:2) as a result.

However, even as neuroscience, psychology and education do move towards an alliance, there are difficulties in reconciling the different traditions of approach, and theoretical, philosophical and practical challenges. The Department for Education in England did not use the term 'brain' in any of its literature until 2006 in an article exposing popular myths such as left- and right-brained thinkers (Department for Education website, viewed 2006). Education is also influenced by numerous factors not traditionally considered by neuroscience, such as the curriculum, the teacher, school resources and the wider social context such family background. In addition, the discipline has been plagued by the existence of 'neuromyths', discussed later, whose uptake has been prolific in schools (Geake 2009, Howard-Jones et al. 2007, Oliver 2011). However, whilst education and neuroscience traditionally operate on different scales (educators may not consider learning at the cellular level, and neuroscientists may not study learning from the progress of a class, school, region or nation (Willingham 2008)), the two disciplines share an interest at the cognitive system level, such as working memory, or impulse inhibition.

Organisations now exist to help bridge the gap between education and neuroscience, such as Learnus (www.learnus.co.uk) and the Centre for Educational Neuroscience (http://www.educationalneuroscience.org.uk/).

Should we be cautious?

However, although teachers have demonstrated a desire to use neuroscience in teaching (Crossland 2010), educational neuroscientists have advised caution when applying it in the classroom, warning that evidence does not yet indicate a need to make any major changes to pedagogy. Instead it is recommended that minor, more subtle changes are incorporated in teaching (Bell, 2016) and that much educational neuroscience offers support for more traditional educational practice rather than radical change. For example, neuroscience describes how memory is formed through 'long-term potentiation' - when neural connections are reinforced by practice and repetition (Garrett 2008, Hardiman 2012), yet "*the importance of practice and rehearsal has been known for more than a century, long before the process of long-term potentiation was identified*" (Alferink & Farmer-Dougan 2010:50, Willis 2006) via the work of researchers such as Ebbinghaus (1913) and Hebb (1949). Evidence from neuroscience provides further support for spacing learning into short sessions repeated over time rather than teaching in a long single lesson (Alferink & Farmer-Dougan, 2010). Importantly, educational neuroscience is providing "*additional data, from a different viewpoint, which can be integrated with the knowledge of psychologists and educationalists*" (Hall 2005:24).

Brain-Targeted Teaching (Hardiman, 2012) (http://braintargetedteaching.org/)

Brain-Targeted Teaching (BTT) is a pedagogical framework which applies research findings from neuro- and cognitive sciences to school education. The approach is devised by Mariale Hardiman (2012) who, as well as being co-founder and director of the Neuro-Education Initiative at Johns Hopkins University, was also a teacher and school principal for more than 30 years. At the time of publishing, BTT was rare in being "*specifically intended for teaching audiences*" (Hardiman 2012:xviii) rather than the research community, and the author stressed it was "neither a curriculum nor a marketed product" (Hardiman 2012:xix). Instead it offers a way to plan lessons "*informed by research from the neuro- and cognitive sciences and research-based effective instruction*" (ibid.) such as how memory, emotion and executive function operate and affect learning (http://braintargetedteaching.org/about_model.cfm). The term 'brain-targeted' is used as opposed to 'brain-based' (a popular term widespread in the nomenclature of commercial schemes) because, as Hardiman asks, doesn't all learning takes place in the brain? However, not all teaching results in learning, so therefore while we may describe learning as brain-based, teaching is not necessarily so. BTT focuses on "*how pedagogy can be informed by knowledge of how the brain learns*" (Hardiman 2012:xxi). The BTT model stems from dissatisfaction with traditional educational debates which focus on accountability for the products of learning, such as exam scores. If "*research from the brain sciences has demonstrated that the essence of learning is about biological changes*" (ibid.) then shouldn't the discussion instead focus on the science of learning? Thus, Hardiman argues for teacher training to include "*at least some knowledge of brain structure and function*" to "*allow educators to become better consumers of scientific research*" (Hardiman 2012:17).

Evidence for BTT.

Students taught with BTT demonstrate "*deeper conceptual understanding and better extension of knowledge, more engaged and happy students and strong state test performance*" (Bertucci, 2006) and teachers who used BTT have "*reported significantly higher personal teaching efficacy than did the matched control sample*", as well as "*higher general teaching efficacy*" (JohnBull et al., 2013:18); An experimental study which centred on randomised control trials of four schools in Baltimore City that integrated all BTT targets, found gains in memory effects with students with learning needs, as well as academic gains for students who learned in arts-integrated units prior to receiving control units (Hardiman et al. 2014).

BTT is "*intended to serve as a bridge between research and practice*" as "*too often, efforts to translate scientific research for use by educators run into serious difficulties*" (Hardiman 2012:xiii). The handbook first identifies neuromyths (such as left- and right-brained thinking, the existence of critical periods of development and that we only use 10% of our brains), and then explains how its principles are embedded "*in broad-based expectations for school climate, instructional planning, teaching practises, and evaluation*" (Hardiman 2012:171). It is only once the learning content, skills and objectives are identified by the teacher, that BTT targets are incorporated into pedagogy. It is thus a sustainable approach. Additionally, this makes BTT an adaptable approach suitable for use across a geographical and education spectrum, from pre-school to university.

Undoubtedly, as Hardiman readily acknowledges, good teachers will already be using at least some, if not the majority, of the strategies outlined in the BTT approach. This does not mean, however, that the model is therefore redundant. BTT is valuable for these teachers in that it recognises good teaching practice and offers a substantial research base and validation for such practice. The framework is also useful for both new and experienced teachers who wish to enrich their practice, with its provision of explanation, guidance and direction in understanding how pupils learn, and practical advice on applying effective teaching strategies.

Evidence from research into student learning is organised into six broad domains, or 'targets', so that teaching is targeted "*to what we know about how we think and learn*" (Hardiman 2012:26). These six brain targets operate holistically and take equal precedence, and all brain targets apply to all stages of teaching. A brief description of them is provided below, together with some examples of observations from this study (Table 1.)

The Brain Targeted Teaching Model		
Target & practical description	**Research/ evidence behind target [2]**	**Some examples observed in science lessons**
1. Establishing the emotional climate for learning. Cultivating routine and familiarity in the classroom; creating a positive environment by praising effort rather than ability; knowing how to deal with emotionally upset pupils; engaging them emotionally in learning; forming positive caring relationships between school, adults and pupils; allowing pupils choice in their learning.	When learning new material, performance declines by at least 30% when students are placed in a stressful situation. Whilst mild stress in certain situations may enhance performance, prolonged stress diminishes the brain's capacity to acquire, keep, and recall information. Thus, "setting the emotional climate for learning may be the single most important task a teacher embarks on each day" (Hardiman 2012:35). Allowing pupils choice over their learning is associated with higher levels of motivation and achievement. Social and emotional learning programmes (such as Circle Time, or SEAL) help children recognise and interpret emotional cues, and research suggests that being able to do so "has long-term effects on social behaviour and academic competence" (Hardiman 2012:49)	Maintaining entry and departure routines (queuing outside the lab and being greeted personally upon entry). Ensuring lab is well-ordered, with equipment drawers and cupboards clearly labelled. Allowing pupils to make mistakes, so that incorrect answers are not embarrassing or humiliating, and pupils are taught not to be afraid to volunteering ideas. Taking several answers from different pupils before confirming which is right, and praising any good thinking processes used (regardless of which is correct). Engaging pupils emotionally in learning by incorporating their names into worked examples or relating subject matter to popular TV or music. More specifically: *Physics*: using examples of pupils' own mass and weight. *Chemistry*: Playing a song about the reactivity series to help the pupils learn it; testing for hydrogen gas is exciting (especially if bungs are expelled due to the pressure of H gas). *Biology:* making cress sandwiches by growing cress (germination), making bread (yeast and microbes) and churning butter by shaking full-fat milk in a jar (nutrition). Providing opportunity for pupil agency in learning; such as allowing them to choose which variable to test in an investigation into factors affecting germination (light/dark, warm/cold, soil/no soil, or a combination); which mode they would like to present findings in (poster, presentation with PowerPoint, or write-up in exercise book).
2. Creating the physical learning environment. Using novelty; appropriate lighting; scents to assist memory consolidation and relaxation; movement around	The physical environment affects learning. Students who study in changing environments perform better on memory measures. Furthermore, children become	Novelty: pupils arriving to a dark lab (black-out blinds, lights off) at the start of a unit on light, and being given a torch to see their way to their desk; projecting an animated image of a beating heart onto a pupil's chest.

the room; the maintenance of an orderly and clutter-free environment.	stimulus-adapted in unchanging environments and seek out their own novel stimulation.	Scents: using rosemary oil (reported to improve recall) in a burner during revision lessons at the end of a unit, and then again during the test; using lavender oil on tissues after break time. Allowing free-movement during practical sessions. Ensuring labs are tidy and well-organised, and that pupils are familiar with the location of equipment and stationery.
3. Designing the learning experience. Providing pupils with a 'big picture' concept map of how lessons or units are connected to one another.	All new learning requires a foundation of prior knowledge. Sequential organisation of curricula traditionally used in teaching fails to connect new learning with the larger concept. The brain organises knowledge around core concepts (schemas). Concept mapping improves memory, understanding and academic achievement.	Displaying a large flow-chart of the unit on an interactive whiteboard at the start of the unit, which is referred to in subsequent lessons; issuing pupils with a diagrammatic representation of the unit to stick into their books/files, allowing them to see how each lesson fits within the unit of work.
4. Teaching for mastery of content, skills and concepts. Improving the acquisition, consolidation and retention of memory through arts integration, via repeated rehearsal, elaboration, information generation, enactment and artistic production; forcing pupils to use 'effort after meaning'; pictorial representation; mnemonics; chunking; and interleaving material (the process of organising learning so that similar tasks are not presented in groups). (Interestingly, the science teaching scheme, Salters Advanced Chemistry, (Denby & Cogill, 2009) orders its	If information is unattended, unconsolidated or unused, it is forgotten. To be retained, information must move from short- to long-term memory. When reviewing research on factors known to improve long-term memory, using arts to improve and reinforce learning is an effective strategy. The following techniques improve memory recall, as they force greater processing of information: *Repeated rehearsal; elaboration* (e.g. by creating pictures/poems);	*Biology:* Drawing a giant heart diagram on the floor in chalk, which pupils then walk through to improve retention of the route blood takes as it flows around the heart; learning actions with equations about respiration/photosynthesis and repeating it for several lessons. *Chemistry:* learning a song about the reactivity series; role playing displacement reactions. *Physics:* composing a rap/song about the order of the planets in our solar system, with a brief description of each one, performed to the class; learning a mnemonic about order of the planets. Using effort after meaning *Biology:* providing thinking time to work in pairs to explain why deciduous trees lose their leaves in winter, with the expectation that they have to report back in 3 minutes.

[2] All references to the substantial body of evidence used to inform the BTT targets may be found in Hardiman 2012; the main principles from evidence is simply listed here.

learning content according to a 'chemical storyline', so that within the story of cars, for example, combustion reactions, the properties of materials and hydrocarbons etc. may all be taught in the same unit).	the *generation* effect (coming up with ideas/hypotheses); *enactment* (performing)*;* exerting *effort after meaning* (puzzling over a problem); using *pictures and diagrams* rather than words.	*Chemistry:* giving pupils 3-5 minutes of silent thinking time to come up with a hypothesis to explain why group 1 metals become increasingly reactive as you move down the group, but in group 7 non-metals the reverse is the case. *Physics:* allowing pupils a set time to work out how to draw a circuit diagram of a staircase switch.
5. Teaching for the extension and application of knowledge, creativity and innovation in education. Teaching pupils to think creatively; teaching the application of skills and knowledge in real-world problem-solving scenarios.	Creativity is not an innate skill and should be taught to pupils; "creativity is in fact an unfixed and impressionable quality" (Hardiman 2012:129). Exposure to other people's ideas positively affects in individual's ability to brainstorm.	Designing and conducting investigations. E.g: *Biology:* the effect of caffeine on brine shrimps' heart rate; measuring peripheral vision. *Chemistry:* chromatography poison pen letters; creating analogies to make a poster about displacement reactions *Physics:* the 'mpemba effect' – can hot water be made to freeze faster than cold; whether magnet strength varies with temperature change.
6. Evaluating learning. Giving corrective feedback, providing prompt feedback and informing pupils of the feedback return date beforehand; scaffolding feedback; allowing continuation of work until competency is achieved; allowing the active retrieval of information; using repeated testing rather than studying to improve information retention; spacing learning events; assessing through multiple modes.	A meta-analysis of studies of factors that improve academic performance, feedback that is both timely and corrective is "one of the best ways to improve student performance" (Hardiman 2012:146). An empirical study showed that student performance was shown to increase in direct relation to promptness of feedback. The active retrieval of information from memory improves long-term retention better than simply reading.	Pupils correcting their own work, using an answer sheet provided by the teacher (forcing them to attend to what they got right, as well as wrong, which is also an effective method of providing prompt feedback, and is more beneficial than simply receiving a percentage grade). Providing feedback continuously during the lesson via questioning. Using testing as a method of learning; pupils being given a few minutes of reviewing last lesson's materials before quick 5-question quiz, as a regular feature of the lesson structure. Returning to previous lessons in a unit and spot-testing.

Table 1: A brief description of the six targets in the BTT model, and some examples observed during the research.

A short summary of the case study findings when BTT was used in practice is provided later.

<u>*Research-based strategies to ignite student learning* (Willis, 2006)</u>

The strategies outlined in Willis (2006) have been formulated by the author who practised as a neurologist for 15 years before training as a teacher in primary, middle and graduate schools in the USA. Her book is a teachers' guide to improving pupils' learning using contemporary neurological findings, which interleaves practical advice with neurological explanations written for a non-scientist readership. Where Hardiman organised the evidence base into six domains, Willis uses four:

1. Memory, learning and test-taking success;
2. Strategies to captivate students' attention;
3. How stress and emotion affect learning;
4. Assessment that builds dendrites.

Each chapter embeds neurological descriptions and explanations alongside specific teaching strategies, so that techniques clearly stem from scientific research findings.

Willis' book was motivated by her desire to train teachers and educators "*to develop and use new strategies that bring the fruits of the research to the students in our classrooms*" (Willis 2006:105) in order to protect pupils, and their schools, from unproven teaching programmes or neuromyths, such as those mentioned previously. She argues that when teachers and educators become more knowledgeable about the structure and function of the brain, it empowers them to ask questions, request research data in order to see if they are representative, unbiased, verified and rooted in sound scientific theory.

A brief summary of the strategies, with some observed examples from William's biology lessons follows (Table 2).

Research-Based Strategies to Ignite Student Learning	
Teaching techniques	**Some examples observed in Biology lessons**
1. Memory, Learning and Test-Taking success	
The process of learning may be described as the creation and reinforcement of the connections between the neurons in the brain. By making teaching multi-modal and multi-sensory, teachers provide pupils' brains with more opportunity to build more dendritic pathways as the "more regions of the brain that store data about a subject, the more interconnection there is" (Willis 2006:4). In practice, teachers should try to present material through numerous senses and link to as many different subject areas as possible so that new knowledge is connected to existing.	**Multisensory teaching** Kinaesthetic: role-playing being an optician explaining long/short sightedness or colour blindness; calculating the speed of transmission of own nerve impulse. Aural and visual: tracing finger along the diagram of a negative feedback loop whilst reading and speaking aloud; describing the effects of drugs to a partner. Reading notes aloud to hear information (activates temporal lobes) whilst simultaneously seeing it (connection with occipital lobes); discussing revision material with other pupils; using colour to make notes more visually stimulating/ interesting.

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<tr>
<td rowspan="7">Presenting material in an innovative way helps to strengthen neural networks.
When information is linked to emotion, for example by associating material to pupils' experiences or involving them in the construction of graphic organisers, such personal involvement and connection will engage pupils more readily. Moderate stimulation to the amygdae makes information more readily transferrable to long-term memory.

Visualisation (e.g. imagining the path that an oxygen molecule may take during gas exchange in the lungs) is another technique to engage "multiple brain pathways" (Willis 200:22), which again makes it more likely that memories will be stored/retrieved.

Breaks during the lesson, even for very short periods of a few minutes, allow neurotransmitter chemicals to be restored so that they are available for future activation.
Information needs to be moved from working memory into long-term memory, by instructing pupils to reconstruct their new knowledge into a different form (relational memory), (e.g. a Venn diagram or by formulating a metaphor).
Finally, repetition and rehearsal transform these memories into permanent memory.</td>
<td>Connecting new and existing knowledge (patterning)
Linking previous lesson on nerves to current topic of synapses.
Linking physics equation (to calculate the speed of nerve impulse transmission) to biology.</td>
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<td>Novelty/surprise
Sparking pupils' interest by presenting them with equipment to use in an investigation, an asking them for ideas.</td>
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<td>Linking of knowledge to emotion and making memories with personal meaning
Discussing emotive issues such as: intensive rearing of chickens versus free range (which is more energy efficient? Why does intensive farming exist?); media coverage of Mexico's change in drug legislation and possible implications.
Frequent linking of topic (e.g. whaling) with contemporary media coverage (the Japanese agreement to cease whale hunting).</td>
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<td>Graphic organisers
Introducing new topics as a flow chart (e.g. negative feedback loop for maintenance of correct body temperature).
Pupils producing a graphic revision resource (mind-map, flow chart, labelled diagram, list or card sort).
Cutting out pictures of animals/plants in food chains to visually represent/compare pyramids of biomass, energy and number.</td>
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<td>Short breaks
The participant teacher preferred to change tasks frequently to prevent fatigue.</td>
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<td>Reconstruction of knowledge into different form
Pupils constructing their own example of a nerve impulse pathway.
Studying a diagram of the eye for 10 s and attempting to draw from memory; creating a rhyme/mnemonic to remember the steps in a reflex; explaining the link between smoking and lung cancer to a partner.</td>
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<td>Repetition
Repeating stages in homeostatic negative-feedback loop.
Orally completing paragraph with missing words as a whole class.
Chanting binominal system mnemonic: KPCOFGS.</td>
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<tr><td colspan="2">2. Strategies to captivate students' attention</td></tr>
<tr><td rowspan="6">Capturing pupils' attention is vital if they are to learn, and Willis offers numerous strategies, such as using humour, making lessons student-centred, priming pupils before a lesson or topic through the use of intriguing signs placed outside the classroom, and devising pupil-centred lessons.

'Teachable moments' describe those unplanned incidents, which might otherwise distract from the lesson objective unless the teacher 'owns it' as a learning event; once curiosity is satisfied the original lesson may be returned to more easily.

Technology can effectively captivate attention, e.g. using 3D graphics from a DVD, or microscopes with time-lapse photography linked to a projector (a much loved piece of kit from my last school which made crystal growth exciting, especially when videos of the time-lapse were set to music and shown to the rest of the class).</td>
<td>Captivating/ priming beforehand
Referring to upcoming test (motivating pupils to concentrate).
Think-pair-share activity: 20 minutes collaborative work to formulate arguments both for and against whale hunting.</td></tr>
<tr><td>Humour</td></tr>
<tr><td>Student-centred lessons (learning in preparation to present/carry out activity)
Researching/writing definitions for five types of drugs (performance enhancers, hallucinogens, depressants, pain relief, stimulants).
Pupils measuring own reaction times.
Teacher asking during one-to-one feedback on controlled assessment: "you know how much effort you put into this – is it worth you doing more?"
Pupils selecting the order in which to complete five tasks: define key words, create a revision resource, complete tables, review pages of text book and produce their own revision resource – quiz, card sort, flow chart, mind-map.</td></tr>
<tr><td>'Teachable moments'
Using a girl's tendency to blush easily was used as a teachable moment on vasodilation.
Taking a pupil's question about inheritance to discuss why they look different to other pupils – "why aren't we all clones?"</td></tr>
<tr><td>Technology
Pupils using their own smartphones/class tablets to research answers to questions about synapses, and to look up images of hybrid animals. Electric microscopes (linked to interactive whiteboard) show slides of nerve cells; watching a documentary about drug use. Developing a science subject page on school website, which posts homework, revision guides, and content of teaching units.</td></tr>
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<tr><td colspan="2">3. How stress and emotion affect learning</td></tr>
<tr><td rowspan="2">Teaching can benefit from an understanding of the detrimental effect of negative stress and beneficial consequence of mild excitement.

Material should have relevance to pupils' lives in order to engage them emotionally in the topic. If the amygdala is mildly stimulated,</td>
<td>Make material relevant to pupils' lives
Discussing why some pregnant teenagers might start smoking [to have lower birth weight babies]; what gateway drugs are; and other issues that may affect adolescents.</td></tr>
<tr><td>Reduce stress</td></tr>
</table>

through excitement, learning is then encoded with emotional meaning and more readily transferred into long-term memory. To reduce unconstructive stress, the classroom can be made predictable in its routines and layout. Additionally, by showing a personal interest in pupils' lives and supporting them when they miss lessons or struggle with a concept, the teacher is able to build trust and confidence, fundamental in the formation of a good relationship with learning. Finally, allowing pupils opportunities to physically move around the classroom during the lesson also has a stress-reducing effect; a feature fortunately intrinsic to the practical nature of science lessons.	Pupils testing each other on lesson material: no public audience. Giving pupils five minutes to look up notes to prepare for a quiz. Allowing collaboration during quizzes. Self-marking. Teacher travelling around the room numerous times in order to check on all pupils' progress and offer non-public help. **Building confidence by listening to ideas** Listening to all pupils' thoughts and ideas throughout the unit; e.g.whether a hybrid zoo existed; if you sat in a cold room would you lose weight; and why dolphins don't have eyelashes. **Physical inclusion** Measuring heart rates before and after running. Allowing movement around the lab.
4. Assessment	
To help improve assessment and performance: reduce test anxiety by familiarising and rehearsing sample questions under test conditions; involve pupils in the creation of assessment rubrics; provide regular feedback; praise pupils for effort and achievement; provide alternative and varied assessment, such as peer-evaluation of notes taken during a lesson; and make it easier for pupils to ask for help and ensuring that oral quiz assessments are not dominated by those who know the correct answers (e.g. using mini-whiteboards, or colour-coded cards). Willis promotes the practice of starting homework in the lesson and providing feedback for the first few questions so that pupils are confident that they know what to do, and how to do it. Pupils can also write summaries of the lesson which they hand to the teacher who displays the ones that provide the best synopsis of the material. This also provides the teacher with an opportunity to identify knowledge gaps and misconceptions. Teachers should be reflexive about their assessment tools, and utilise pupil feedback to confirm whether or not teaching has resulted in the desired outcome as "sometimes what one thinks was taught is not what the students	**Specified praise** Providing public and specified praise of correct answers (interestingly, Willis does not suggest that praise should be directed at effort as in BTT). **Multiple forms of assessment** Completing tasks in notebooks; peer assessment via oral testing; giving one-to-one feedback on homework; quick quizzes in class; formal controlled assessment; coursework. **Frequently assessing during the lesson (quick quizzes) in order to spot gaps** **Pupils able to ask for help** Establishing rapport with pupils such that they feel able to ask questions. **Starting homework during lesson** Pupils could ask for help/clarification. This increased pupils' security and confidence in completing the task at home. **Assessment return: appropriate timing and form** Teacher circulating lab in order to provide discreet one-to-one feedback with pupils regarding their controlled assessment during a class task. Other pupils appeared to be unaware of the

learned" (Willis 2006:87). It is also important to consider when, and in what form, feedback is returned: publication of results can cause considerable distress to some pupils, and if work is handed to the class simultaneously, there is the risk of boasting and comparing, and (more importantly) the teacher's meticulous feedback is skimmed or ignored.	feedback, thus achieving Willis' aims of individual tailored feedback.

Table 2: A brief summary of Willis' techniques and examples observed in William's biology lessons.

Using the approaches in practice: a brief summary of findings.

It is important to note that in this case study the experiences of four participant teachers were examined in depth. Therefore, the findings are not necessarily generalizable to other cases, but the teachers' and pupils' experiences are interesting and valuable in their own right.

Of the four approaches (see part 1), BTT and Willis' book were easier to implement than CASE and CLT: they were written specifically for teachers and related to classroom scenarios, whilst maintaining the flexibility to be used across different age groups (and subjects), and required little preparation once familiarisation was achieved.

As in part 1, the participating teachers appeared to gain as much from being provided with research-based evidence in support of their existing practices as they did from learning new techniques.

<u>BTT.</u>

George summed up his approach to science teaching: "*I always think that if the children enjoy being in the classroom then they will learn much more*", and this was evident in their enthusiastic involvement in lessons, even if they did struggle with some aspects. He described BTT's methods as being "*really applicable*" to science, as it encouraged him as a teacher to place pupils at the centre of the lesson, to make the lessons fun, and to understand how and why these techniques help learning.

George was very enthusiastic in incorporating the six targets in his teaching. As expected, some targets were easier to achieve than others: he bought a scented candle to aid relaxation, although this was not potent enough and any effects were lost when a practical ^^^ involving Bunsen burners was carried out. Subsequently, he found using a vaporiser was more effective and pupils remarked positively as they walked into the room that they liked the smell, and at the end of the final term George said that "*the oils definitely helped with my Year 8 revision classes*", although the collection of evidence beyond his opinion (anecdotal) was beyond the scope of the research. Other targets, such as the introduction of more role plays and songs required a little more time and effort, but both George and his pupils reported positively.

As the action research progressed, George made further changes to his teaching practice. He achieved the instantly positive effect of carrying out a thorough tidy of the laboratory in order to achieve an 'orderly and clutter-free environment': "*the surroundings form quite a large area of the BTT research and I do not feel I have given this area a real go as yet*".

Meeting other targets took longer to develop and to rehearse until they became second nature, such as the more conscious engagement of pupils emotionally in learning by linking new knowledge to their experiences and interests (for example, George referred to platinum as being the sort of metal that gangsters prefer to wear I don't understand that, and made pupils aware of the comet season so that they might observe them first-hand). George also reported that he had to keep reminding himself to praise pupils for effort rather than ability, and found it initially challenging to provide pupils with big-picture concept maps.

By the end of the research period, George said he had had "*lots of success with including the children in the planning of our lessons. Show them the big picture and they really do feel comfortable when we progress through the topic. They know what to expect*", echoing Hardiman's concern in Brain Target Three that "*too many times they [pupils] are just learning isolated facts with little connection to their prior knowledge of other content*" (Hardiman 2012:81). George said that he liked all the techniques and wouldn't stop using any. However, he cautioned that "*I think it's just important to use different techniques with some classes and adapt my approach depending on the reaction and response of the class*".

At the end of the first term, George reported that he "*really like[d] this approach because I agree with the flexibility of teaching that it promotes*", and that it seems to incorporate all the "*best bits*" from other theories and approaches. The importance BTT gives to the formation of a positive and caring relationship between the pupils and their teachers struck a chord with George, who told me: "*I believe that the most effective precursor to learning is done prior to entering the classroom. If the student has a good relationship with the teacher and is in a good mood they will be much more inclined to learn. BTT follows this*" He described the approach as giving him "*more confidence to allow more time for the fun areas of the lessons*"; when I asked George which parts of the unit he was particularly pleased with he described the lesson when pupils "*produced and performed a little role play*". Although these thoughts in themselves do not necessary demonstrate a *change* in George's attitudes, it has certainly caused a change in self-assurance in his teaching style. In his words, BTT "*gives me backup – published literature – for teaching the way that I enjoy, and the way* *that I feel is of most benefit to the children*". George's description of BTT being "*immensely*" easy to incorporate into planning indicates a high likelihood of sustained use.

BTT for pupils

Mid-way through the research period, George told me that BTT allowed a great deal of "*fun*" into lessons, and that this was important as he believed "*that if at this age, we can get children to think they enjoy their science lessons then genuine interest in how and why things happen will naturally develop*". He said "*they love being out of the classroom*" such as when they changed the car tyre, played golf and balanced the seesaw, echoing some of the aims of brain target two (novelty) and five (creativity and innovation).

It is important to note that George's class was small and included several low ability pupils, whose confidence was relatively low. Consequently, in order to engage them in science, George emphasised the enjoyable and practical aspects of the subject. With this in mind, it is not surprising that pupils highlighted the "*fun*", "*exciting*" experiments and investigations as being preferable to writing a lot. Their lack of confidence was apparent: they described themselves as being "*confused*" at times, and "*a bit slow, like me*". However, they explained that George's approach was helpful to their learning because when they were engaged they remembered better: the experiments were "*different*" and "*exciting*" (see figure 1). I suspect that other academic subjects are not able to offer quite the same level of practical involvement and thus engagement.

Figure 1: Photograph of George's lesson about moments and turning effect, taken by one of the pupils: it is vital that they calculate the correct force to apply, at the correct distance from the fulcrum. Employing high-stakes and exciting strategies such as this engaged them very effectively.

Research-based strategies to ignite student learning.

Changes in teaching practice, beliefs and attitudes

William found the book accessible and easy to read: "*a massive bonus is that its short – it can be read in an evening*", but that, more importantly, "*putting the concepts into practice can be rapid*". He believed that "*at last half is normal good practice anyway, but it's equally worthwhile to read and pick up other bits*".

In addition to his existing practice, William first tried techniques such as multisensory teaching and approaches to reduce stress in the first cycle of action research. He reported that he particularly enjoyed introducing a better use of technology by allowing the pupils to use their own smartphones to conduct research in the lessons, and was pleased with the effect of "*linking learning to [pupils'] own experience*" as a way of engaging them emotionally in learning.

By the middle of the research period, William told me that "*I'm enjoying it. It's easier to do now; it's becoming more natural to think about – as with anything new*". He had managed to incorporate the great majority of Willis' techniques into his teaching, and when I asked him which methods he particularly favoured he said: "*I like the assessment return, when it's one-to-one*", as recommended by Willis, but complained that unfortunately he lacked the time to see all pupils in this way in one lesson. He also liked "*anything involving them talking, and me listening to their ideas – even if they talk rubbish I'd rather that they talked rubbish to me and we can discuss it*", following Willis' recommendation that to build pupils' confidence teachers should listen to their ideas properly. William also liked to give pupils specified praise as "*it's easy to use; requires no extra effort in planning, but can have a massive impact*". During our final interview, William said he had "*enjoyed using the Willis ideas and have found them to be stimulating and interesting for me, as well as the majority of the students involved*".

Since using Willis' approach, William said that there were four specific techniques he particularly liked. He was encouraging pupils "*to use technology to research and investigate concepts*", and said that he had "*also begun to prime students more*" and to "*allow thinking time*" so that pupils don't feel "*overly pressured*". He also believed that "*using a variety of styles and approaches*" is the "*best method of ensuring learning is developing*".

Although he described the book as "*at least half is normal good practice anyway*", it was clear that William appreciated the scientific verification of many of the techniques he already employed; it had the effect of increasing his confidence to use these 'good practice' methods. He explained that "*the science as to why things are as they are is fascinating … it was useful to me. I was already using some of the techniques discussed, but have now learned others as well as understanding more about the theoretical basis for their use*". At the end of the academic year when asked if he would continue to use *Research-based strategies to ignite student learning*, he replied "*Yes. It's changed how I approach my teaching*".

Research-based strategies to ignite student learning for pupils

William reported that it "*took the pupils a few weeks to make the transition*" to becoming more independent learners and that eventually they "*find the learning easier*" as they "are forced to engage with the subject and actively explore the understanding". Interestingly, following the first unit test, his class (second set of four) scored higher than the first set; William said he'd like to believe that this was due to the approach (but clearly this was optimistic speculation, and in subsequent units the class performed as expected). He felt that his primary challenge in implementing the approach had been to persuade the pupils that they *were* able to learn in a more informal, independent, student-centred environment; that this attitude would be beneficial to future studies: "*It's more about convincing them that they're capable – giving them the confidence. If and when they carry onto A-levels, they're ready to go … there's no spoon feeding; they have to think for themselves … controlling their own learning*". Equipping his pupils with the skills to ask "*for help when needed*" was important.

The pupil focus-group interview indicated that the predominant change in learning outcome was that learning was becoming more independent. Text books reportedly played only a limited part in the teaching process, in favour of William's more student-centred interpretation of topics which required self-regulated, and often collaborative, work to complete tasks. Pupils said that they were indeed engaging emotionally with the subject, and found the lessons more interesting than their other conventional 'chalk and talk' ones. The relaxed, low-stress environment was a prominent feature of the lessons and regarded favourably on the whole, generating comments such as "*with other sets you're always like, by yourself, straight set out, whereas here it's not just on the board where it's boring*"; "*You're not pressured – it's more informal, so you can work. He sets things that you can do with partners*". However, a couple of pupils were concerned that for optimum work, there should also be firm expectations of pupil behaviour and achievement. One pupil said of William's lessons "*I remember stuff in them … I just find it easier to remember than writing*".

By the end of the research period, William stated that "*the majority of students have responded well to the teaching and learning styles used, but there are some individuals – under-confident girls – who have not always engaged with the techniques*"; instead, these pupils wanted "*to be told information for regurgitation in a classic transmission model of learning, rather than having to become involved in some of the techniques – like open questions or applying ideas to [new] contexts – which encourages understanding*". In conclusion, William believed that "*learning outcomes and progress have improved … for some more than others … those that have engaged have undoubtedly improved more and it is now for me to try and engage those others more into the process*".

Conclusion.

This case study indicated that both approaches were easy to access and implement, and provided neuroscientific evidence for much existing good teaching practice. This was valuable in that it increased both William and George's confidence in using some of their own teaching practices, as well as increasing the likelihood of adopting other new techniques. More data, collected from a far larger sample size and across several schools, on the effect of using educational neuroscience in teaching science would be very valuable, particularly to help inform the decision of whether, and how much, educational neuroscience should be included in teacher training. *It would be very valuable if other teacher-researchers tried and evaluated some of these approaches, particularly those from educational neuroscience that are more recently published (such as the two detailed in this paper0 and thus have yet to receive the same depth and breadth of evaluation.*

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