Using educational neuroscience and psychology to teach science. Part 1: A case study review of Cognitive Load Theory (CLT) and Cognitive Acceleration through Science Education (CASE)

Rebecca Torrance Jenkins

ABSTRACT This article is the first of a two-part series that explores science teachers' and their pupils' experiences of using different pedagogical approaches based on understandings of how brains learn. For this case-study research, nine science teachers were interviewed and four teachers self-selected to trial a pedagogical approach, new to them, from cognitive psychology and educational neuroscience, using an action research framework for between one and two academic years. Both teachers' and their pupils' experiences of using the approach were explored, and data were collected via observations, interviews with teachers and focus-group interviews/written questionnaires with pupils. As in case study research, each case was examined in depth, and consequently findings are not necessarily generalisable to other cases. However, it would be valuable if other teacher-researchers tried and evaluated some of these approaches, particularly those from educational neuroscience, where recommendations are based on relatively recent research findings. Part 1 will focus on two approaches rooted in cognitive psychology: Cognitive Load Theory (CLT) and Cognitive Acceleration through Science Education (CASE); part 2 will focus on approaches from educational neuroscience: *The Brain-Targeted Teaching Model* (Hardiman, 2012) and *Research-Based Strategies to Ignite Student Learning* (Willis, 2006).

The school subjects of biology, chemistry and physics easily lend themselves to incorporating many of the teaching methods proposed by both cognitive psychology and educational neuroscience, owing to their multimodal nature of teaching and learning – via practical work, teacher demonstrations, pupil collaboration, investigations, and so on – all normal and, to varying degrees, commonplace practices.

The pedagogical approaches explored here derive from the cognitive psychology of Vygotsky. Cognitive Load Theory (CLT) was developed as a set of '*guidelines intended to assist in the presentation of information in a manner that encourages learner activities that optimise intellectual performance*' (Sweller, van Merrienboer and Paas, 1998: 251) by examining the effects of the distribution of different cognitive loads on learners' brains. It is reinforced with empirical findings that demonstrate the positive effects of managing cognitive load management on learning. However, it is not a 'classroom-ready' approach, and teachers should draw from the theory those parts that can be applied to their teaching (examples are provided later). Cognitive Acceleration through Science Education (CASE) was first developed in 1981 and is a highly defined programme for teaching scientific topics, such as levers in physics, alongside the usual curriculum. CASE is a type of guided enquiry that aims to challenge pupils' existing levels of thinking in order to encourage the construction of knowledge and how they reflect on their own thinking (metacognition). CASE relies heavily on the pedagogy of the lesson; that is, the way the materials and concepts are taught by the teacher, and ideally should be implemented across the whole school.

By no means are the aims of the approaches mutually exclusive and nor do they operate in opposition; in fact, several of their ambitions are explicitly shared. For example, both aim to equip pupils with lifelong flexible thinking and problem-solving skills, promote the practice of multimodal teaching and strongly recommend that content is learned before being applied to an investigative situation. More detail about each approach now follows.

Cognitive Load Theory

The capacity limitation of our working memory is a defining feature of the human cognitive system, and Cognitive Load Theory (CLT), developed by John Sweller in 1988, provides teachers with a pedagogical approach that manages the allocation of cognitive resources during learning. The theory, underpinned by theoretical research and empirical findings, provides a '*convenient and effective way*' (Plass, 2009: 5) to design teaching materials in relation to the cognitive load they impose. By understanding how learners construct knowledge, teachers can create materials and shape learning tasks to optimise learning (Paas, Renkl and Sweller, 2004; Sweller, 1988): '*knowing how students learn and solve problems informs us how we should organise their learning environment and without such knowledge, the effectiveness of instructional designs is likely to be random*' (Sweller, 2004: 9). Reducing task-irrelevant information and designing activities and materials in a certain way allows pupils to prioritise mental effort on processing *task-relevant* materials, allowing actual learning to take place (knowledge to contribute to long-term memory), rather than on activities that do not. CLT was never intended to be a theory about learning, but instead an explanation of '*the relation between the human cognitive architecture, instructional design, and learning*' (Moreno and Park, 2010: 20).

Sources of cognitive load

CLT initially concerned itself with the cognitive processes required to solve problems and acquire 'schemas'. A term that preceded the development of CLT, 'schemas' may be described as '*cognitive constructs that incorporate multiple elements of information into a single element with a specific function*' (Paas, Renkl and Sweller,

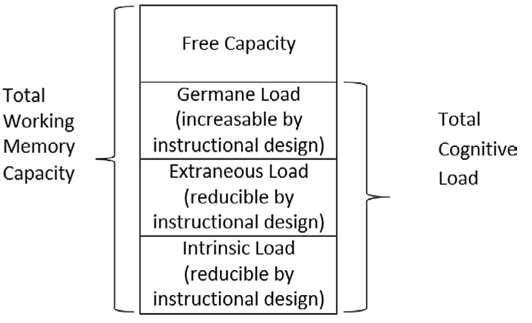

Figure 1 The additivity hypothesis: available working memory space is determined by the combined size of intrinsic, extraneous and germane loads (adapted from Moreno and Park, 2010: 18)

2003: 2). An example of a schema could be the topic of 'atoms', which in fact incorporates the multiple elements of atomic structure (such as protons, neutrons and electrons), electron shell configuration, atomic charge, reactivity and so on.

CLT then focused more specifically on the allocation and type of cognitive resources employed by the brain during learning, during which pupils may be subject to cognitive load from three discrete sources: *extraneous, intrinsic* and *germane*. Interestingly, '*all three memory loads can now be measured through fMRI*' (Fadel and Lemke, 2008: 15), in which functional magnetic resonance imaging (fMRI) measures the activity of the blood flow round the brain. It is important for teachers to understand the differences between these three loads, so that they can reduce any unnecessary load and shift effort into tasks that optimise learning. They are explained briefly in Table 1.

The additivity hypothesis (Figure 1) assimilates the three load sources into a holistic concept of cognitive load: as understanding of a subject increases, the entailed processes require less attention, such that in time, '*they become more automated, freeing cognitive resources for other activities*' (Sweller, 1994: 298).

Examples of practical strategies from CLT to use in the classroom

In this research, it was found that CLT required considerable 'translation' from around 12 relevant research articles into a format that could be readily understood and applied by the participant teacher in the classroom. Accordingly, the principles and effects from CLT have been adapted from Plass

Table 1 Sources of cognitive load

Name of cognitive load	Definition	Example
Extraneous load	Tasks that do not contribute to learning (Sweller, Chandler, Tierney and Cooper, 1990). With careful planning, existing tasks can be redesigned to reduce or remove extraneous load while preserving the learning content. This makes CLT particularly attractive, and valuable, to teachers.	Copious note writing when fill-the-gap sheets could be provided; writing out questions before answering them; copying complex diagrams or tables without actively engaging in them.
Intrinsic load	Tasks that require the simultaneous processing of numerous elements carry a greater intrinsic load. This makes them more difficult to learn. However, '*if elements can be learned successively rather than simultaneously because they do not interact, intrinsic cognitive load will be low*' (Sweller, 1994: 295). It was thought that teachers had '*no control over intrinsic cognitive load*' (Moreno and Park, 2010; Paas *et al*., 2004), but more recent research states that '*it can be reduced by scaffolding the information*' (Vogel-Walcutt *et al*., 2011: 135), which, in the author's experience, good teachers know and do anyway.	Balancing chemical equations requires the simultaneous processing of several elements, such as: knowledge of chemical symbols; an understanding of the law of conservation of mass; the trial-and-error process; coefficients (the number of molecules/ atoms involved in a reaction) and molecular structure.
Germane load	The actual *learning* load. The effort a student expends in constructing and storing schemas in long-term memory; the cognitive resources dedicated to constructing and systematising schemas, and not on other mental undertakings. However, simply reducing extraneous or intrinsic load does not automatically increase germane load; the freed load capacity must contribute to schema acquisition (Sweller, 1994).	When students convert working memory to form new long-term memories. Evidence of germane load may be seen when students are able to apply newly acquired knowledge to a novel situation.

(2009), Sweller (2010) and Sweller, Ayres and Kayluga (2011) to form a 'checklist' in order to make it more straightforward for teachers to access and thus implement (Table 2).

Cognitive Acceleration through Science Education (CASE) and Thinking Science

Thinking Science is a programme of guided inquiry based on materials developed from the CASE project in the 1980s by a team at King's College London (www.kcl.ac.uk/sspp/departments/education/research/Research-Centres/crestem/Research/Past-Projects/Cognaccel.aspx). Extensive research has evidenced significant improvements in pupils' understanding of science if cognitive acceleration is practised over a period of several years (Adey, 1999; Shayer, 1999; Adey, Robertson and Venville, 2002; Adey and Shayer, 2011; Oliver and Venville, 2017). Furthermore, Thinking Science (www.letsthink.org.uk/) links well to the 'working scientifically' aim in the National Curriculum in England (taught in all local-authority-maintained schools, but widely used as a guide for other types of school such as academies and independent schools), in which 'working scientifically' '*must always be taught through and clearly related to substantive science content in the programme of study. Teachers should feel free to choose examples that serve a variety of purposes*' (Department for Education, 2015). Thinking Science comprises 30 lessons for pupils aged between 11 and 14 years which run parallel to, and in addition to, existing curricula, and may be used in lessons where science is taught as an integrated or separate subject. Each Thinking Science lesson is designed to take an hour or less, and does not aim to teach new semantic knowledge; instead, lessons take the form of a practical session that provides a context and scenario in which pupils learn to develop specific cognitive competencies with deliberated and careful guidance

Table 2 'Checklist' to assist teachers' use of CLT in teaching (developed by the author from Plass (2009), Sweller (2010) and Sweller, Ayres, and Kayluga (2011))

Cognitive Load Theory	
Reducing extraneous load	
Worked example effect	Using **worked examples** instead of open problems, where appropriate (although if pupils are preparing for exams in which open questions are posed, they will obviously need the opportunity to practise them).
Goal-free principle	Provide pupils with **goal-free tasks** rather than means-ends approaches. (A means-end procedure often results in a problem solver working backward from the goal to the problem given, before then working forward from the givens to the goal. While this strategy is effective in obtaining answers it has a necessary consequence of inducing very high levels of cognitive load.) A 'goal-free' problem focuses the student on the information provided (the given data) and using it wherever possible. A forward working solution approach is automatically used, which imposes very low levels of cognitive load and facilitates learning (Owen and Sweller, 1985; Ayres, 1993). For example, 'A particle starts from rest and is accelerated at 10 m/s^2 for 5.5 seconds. Find what you can.' is goal-free, and has a smaller cognitive load than 'A particle starts from rest and is accelerated at 10 m/s^2 for 5.5 seconds. What is its terminal velocity?'
Completion principle	Provide pupils with partially solved problems, which they must finish.
Redundancy effect	Reducing the need to process sources of information that do not contribute to schema acquisition, such as by not including a verbal description of the flow of blood through the heart when the diagram alone is all that is necessary.
Split-attention effect	Making sure that information is not presented to the same sense from different sources at the same time. Learning is harmed when '*dynamic information from two (or more) different sources is presented simultaneously*' (Plass, 2009: 4) as it entails a higher cognitive load than if the information is presented multisensually. For example, presenting an animation of the heart with an audio-description (visual/audio) has a lower load than simultaneously reading a description while also looking at a diagram (visual/visual).
Guidance fading effect	Scaffolding learning using level-appropriate guidance, withdrawing support as pupils become more accomplished.
Contiguity principle	When related information is presented closely in space or time, then learning is improved (Plass, 2009). When teachers remind students of the link between new knowledge and prior, they are employing the contiguity principle. *Spatial contiguity*: integrating labels with diagrams eliminates the need for a visual search to connect two sources of information rather than using a separate key (see Figure 2b). *Temporal contiguity*: teaching related topics one after the other so that pupils don't have to recall and relate two topics taught in different time periods. For example, learning about photosynthesis immediately after respiration enables students to understand that the two processes take place within a plant organism and how both are interrelated; being taught these two processes separately would exert a greater extraneous cognitive load when original schema are recalled and related to the new information.

Table 2 (*continued*) 'Checklist' to assist teachers' use of CLT in teaching (developed by the author from Plass (2009), Sweller (2010) and Sweller, Ayres, and Kayluga (2011))

Cognitive Load Theory	
Managing intrinsic load	
Isolated/interacting elements effect (also known as simple-to-complex strategy)	Learning is enhanced if very high element interactivity is first presented as isolated elements followed by interacting elements versions, rather than interacting elements form initially. For example, learning symbols for the elements has isolated interactivity, but balancing an equation has high interactivity.
Low- to high-fidelity strategy (accuracy)	Practising tasks in an environment where accuracy is less important than the development of skills, before progressing to situations where accuracy plays a more central role. For example, in practical science lessons, novices learn how to make simple electric circuits, test magnetism and test malleability in separate lessons. In a later lesson, once expert, students could be required to use these procedures in the same investigation: testing various metals' properties (conductivity, reactivity with water, magnetic properties and malleability) with very little guidance from the teacher.
Optimising germane load	
Variable examples	Providing novice pupils with examples or tasks that have similar surface features (topic), but different structural features (calculations/methods) enhances learning more than if similar structural features are grouped with different surface features. For example, group speed/distance/time problems together, each of which requires a different computation. (However, for experts, learning is enhanced if problems are grouped by structure than by surface: using the same calculation but for different scenarios).
Self-explanation principle	Asking pupils to explain a piece of information, with prompts if required, instead of using worked examples.
Expertise-reversal principle	Adapting instructional design to pupils' level of expertise so that it isn't too difficult for new learners or too easy for experts. For example, a study by Schmidt *et al.* (1989) (cited in Schmidt, Loyens, van Gog and Paas, 2007) split pupils studying osmosis for the first time into two groups. Both groups studied text on osmosis, after one group had first discussed an osmosis problem and the other studied an unrelated problem. At this early stage of learning about osmosis, the group with prior experience remembered significantly more (over 40%) than those without. Interestingly, when another group of pupils who had studied osmosis to a more advanced level, and consequently called 'experts' by the researchers, were presented with the same problem, these experts '*did not gain as much from the experimental treatment as the novices*' (Schmidt *et al.*, 2007: 93), demonstrating a learning gain of only 11% relative to the group who had studied the unrelated problem. A multimedia environment (such as a computer programme where users click on a term to access a definition) can reduce expertise reversal effect by providing, for example, '*definitions on demand, rather than by default*' (Plass, 2009: 3). However, it is '*difficult or even impossible for pre-planned instruction to take the expertise of individual learners fully into account*' (Kirschner, Sweller and Clark, 2006: 79).
Completion strategy	Providing pupils with completion tasks for which they must tackle increasingly larger parts of the solution, as they become more expert.

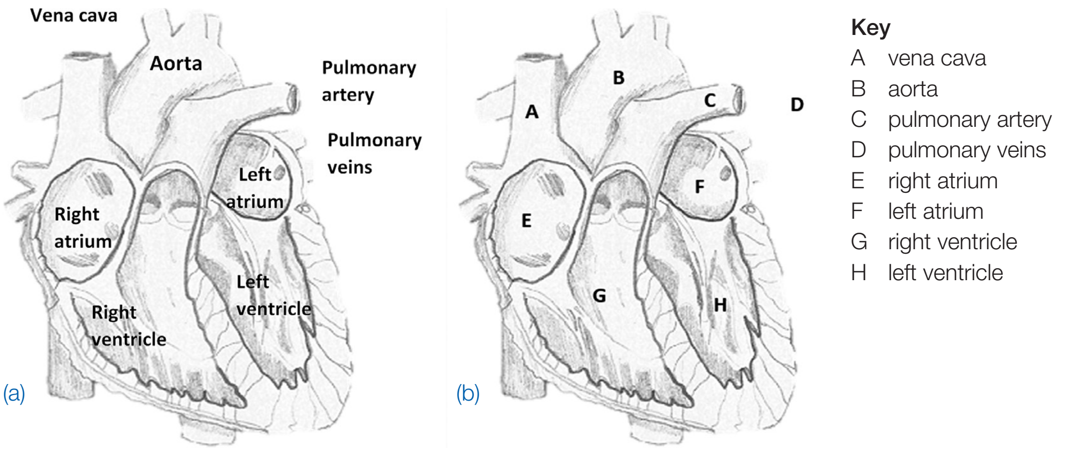

Figure 2 The spatial contiguity principle: (a) reducing extraneous load by integrating labels with visualisation; (b) extraneous load is increased when labels are not integrated with visualisation

from a teacher, as a whole-class or during group work. Thinking Science materials are available as hard copies or on a CD, which installs the 30 lesson plans, teachers' notes and pupil worksheets onto a computer to be printed out when required.

The Education Endowment Foundation (EEF) (2016) carried out effectiveness trials to test whether a CASE intervention can work on a large scale (50 schools). It should be noted that the '*evaluation provided no evidence that Let's Think Secondary Science* [LTSS] [CASE materials adapted for the study] *had an impact on science attainment*' (EEF, 2016). However, it is disappointing that, although both control and experimental groups performed the same when tested with the 2009 science at key stage 3, tier 3–6, paper 2, the study '*did not test for the effect of LTSS on cognitive reasoning nor assess how gains in cognitive reasoning correlated to gains in student achievement*' (Let's Think Forum, 2016: 1). The existing data supporting CASE assert that its effects are long term and, with this in mind, the EEF states that it will collect more data on the longitudinal impact of the study by measuring the impact on GCSE results once they are available for the participating students. Interestingly, other, more recent, research demonstrated that the Thinking Science programme, when used over the recommended two-year length, produced '*significant cognitive gains compared with an age-matched control group over the length of the program*' (Oliver and Venville, 2017) in seven Australian high schools.

CASE was first developed in 1982 after the discovery of a '*significant mismatch between the demands of the curriculum and the type of thinking available in the population*' (Adey, 1999: 4) and is presented not as an alternative science curriculum, but as an intervention in the science taught to pupils aged 11–14 years. CASE operates as a '*process of accelerating students' "natural" development process through different stages of thinking ability*' towards that described as '*abstract, logical and multivariate*' (Adey, 1999: 6), termed by Piaget as '*formal operational*' thinking. To achieve thinking proficiency, pupils work towards competency in five thinking skills, known as 'the five pillars of CASE wisdom', which are incorporated into specific curriculum aims, summarised in Table 3 and Figure 3.

Despite much empirical research indicating the significant positive effects of the long-term use of CASE, its use is not commonplace in schools; perhaps the lengthy time frame and substantial input required from teachers offer some explanation for this. It was to these very reasons that the EEF attributed the lack of success in their short-term study. As with any form of guided inquiry, each stage must be carefully constructed and led by the teacher, who frames and provides the learning experience. Cognitive conflict, for example, '*must be maintained and this can only be done by the teacher through close questioning*' (Adey, 1999: 7), and concrete preparation can only be done thoroughly if it is prepared and monitored by the teacher. There are several intervention programmes that can be described as fostering '*cognitive acceleration*' and '*none could be regarded as a quick fix*' (Adey and Shayer, 2011: 1). It requires

Table 3 The 'five pillars of CASE wisdom'

Pillar	Description
1. Concrete preparation	Students prepared for a problem (including context, associated language, apparatus), and misconceptions are prevented.
2. Cognitive conflict	Students presented with a problem for which they need assistance (from teacher or peer) to solve/understand. Constructive mental work takes place.
3. Construction	A lengthy process whereby students construct knowledge with the teachers' guidance. It operates in the 'construction zone', a term developed from Vygotsky's 'zone of proximal development'.
4. Metacognition	Students are able to think about their own thinking – such as how they approached a problem, and which techniques worked best. This is '*time-consuming and quite difficult to do*' (Adey, 1999: 6).
5. Bridging	Achieved when students are able to connect new information with existing knowledge, from science or even different subjects and real-life experiences.

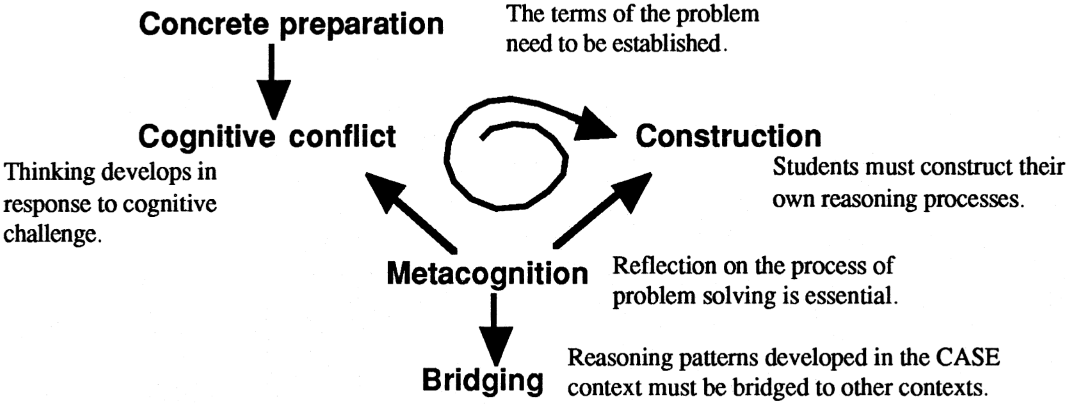

Figure 3 The 'five pillars of CASE wisdom'; reproduced with permission from Adey (1999: 6)

skills that, in my own experience at least, are not necessarily taught during teacher training (mine took place between 2004 and 2005 and did not include such training); for example, Adey describes metacognition as being '*time-consuming and quite difficult to do, and teachers and students need a lot of help and encouragement initially to become more metacognitive in their approach*' (Adey, 1999: 6). Furthermore, Thinking Science operates in addition to the workload imposed by the National Curriculum or specific examination requirements.

Using the approaches in practice: a brief summary of findings

It is important to note that in this case study the experiences of two participant teachers were examined in depth. Therefore, the findings are not necessarily generalisable to other cases, but the teachers' and pupils' experiences are interesting and valuable in their own right. Both of the participant teachers, Emma and Sam, undertook several cycles of action research, where the findings from each cycle fed into the next and informed any changes to teaching.

Although the ease with which teachers could implement the pedagogical approaches was not used as a criterion for their selection (instead, teaching approaches were selected on the strength of their scientific integrity, reliability and empirical evidence), in practice this made a difference to how easily they were used by the science teachers. CASE (as well as the pedagogical approaches from educational neuroscience, discussed in part 2 of this series), with the ready-to-go format, was more attractive (in theory) to all nine of the teachers interviewed at the outset of the research. They perceived the approach as being easier to implement than CLT and said they preferred to be trained in the practical delivery of a new approach rather being faced with the task of translating complex research findings into a practically applicable format. Findings from both preliminary interviews and planning discussions with the teachers concurred fully with Guskey's observation on teacher continuing professional development (CPD) that what teachers '*hope to gain through professional development are specific, concrete, and practical ideas that directly relate to the day-to-day operation of their classrooms*' (Guskey, 2002: 382). One of the participant teachers' sentiments supported this: when asked if he'd like to be able to read more research he said '*No. I'd just like to be fed the good stuff*'.

Interestingly, 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 (Torrance Jenkins, 2014). This brief general discussion will now be followed by more specific remarks about teachers' and pupils' experiences of using CLT and CASE.

Findings from using CLT

Changes in teaching practice, beliefs and attitudes

CLT, the result of decades of collaborative work and underpinned by empirical findings, was so far removed from practical teaching that I had to make Emma a checklist of the principles, with examples (Table 2). It was thus difficult to agree that CLT does provide a '*convenient*' (Plass, 2009) way to design teaching materials; it is unlikely that other teachers will have the time, inclination, and access that I had, to extract the practically applicable techniques from the literature. Thus it is perceived that, at present, the likelihood of CLT's use being as widespread as CASE is low, but Goswami's conclusion that teachers prefer '*being "told what works"*' (2006: 6) was certainly the case in this research.

Although Emma commented that she '*was tending to do most of the* [CLT] *things anyway*', she had also '*picked up some ideas*' from CLT, describing it as being '*easy enough to use*'. She found the consideration and management of different loads '*useful*', and before the end of the first action research cycle was already using some techniques with other classes. Emma found even a simple reduction in extraneous load had a positive effect on her pupils' learning. However, she struggled to find '*the time to prepare*', although this improved with familiarity of the approach.

Much of the first action research cycle focused on familiarising Emma with those parts of her existing practice that were advocated by CLT (predominantly the reduction of extraneous load via the use of a fill-the-gaps pupil workbook). In subsequent cycles, she more consciously implemented the principles of CLT by using a worked example of writing ionic formulae for transition elements followed by some fill-the-gap tasks, creating printed tables for students to record investigation data, and omitting any written task description that would have been redundant to the learning. Emma said that much of CLT was a part of good teaching practice, and in these instances I would agree that good teachers withdraw guidance as pupils became more proficient.

Emma became increasingly proficient at managing intrinsic load by teaching the more challenging topics to pupils in a non-interacting format when they were still novice, interacting the component parts only once expert status (relative to their age and stage) was achieved. Her approach is supported in the literature, because if '*elements can be learned successively rather than simultaneously because they do not interact, intrinsic cognitive load will be low*' (Sweller, 1994: 295). For example, she provided pupils with opportunities to first learn how to work out the ionic charge of transition elements, and only then set them the task to identify the full formula of a transition metal compound. Similarly, she optimised germane load using the 'expertise reversal principle', ensuring novices were not faced with too difficult a task, or vice versa, which reduces learning (Sweller, 1994).

CLT for pupils

Year 7 (age 11–12) pupils reported very positively about CLT and wanted to continue to learn using the approach (however, it must be acknowledged that although they could compare science lessons to other subjects, being in the first year of the school meant that this was their only experience of science lessons). Reasons for liking the fill-the-gaps workbook were: for revision; in case they missed a lesson; it prevented them from becoming lost; and it reduced the time spent writing. Consequently, '*the book is a lot faster, and it helps us. So you can do extra stuff* [more learning] – *you have more time*', concurring with Plass (2009) that the reduction of task-irrelevant information, by designing instructional activities and materials in a certain way, allows pupils to spend mental effort on processing task-relevant materials.

All the year 8 (age12–13) pupils reported positively, telling me '*we are learning better*' and '*I have retained the information better*' when CLT was used, although for the pupils who had been taught by Emma the previous year, what comparison they used to measure 'better' against was difficult to establish, something one pupil pointed out: '*I couldn't possibly tell as I have been taught this way for my whole senior school chemistry life* [18 months]' (a comment that also indicates that he was unaware of the extra techniques from CLT that Emma was using). Nonetheless, their very positive responses, given anonymously via written questionnaires, remain valuable. They too identified the benefit of reducing extraneous load, writing that: '*we only learn what we need to know, and don't learn unimportant things*' and '*the crucial elements that are core to learning chemistry are the only things we need to do, without having to waste time with unnecessary things*'.

They relished practical experiments, valuing them for the opportunity they provided to learn, stating for example that '*they help learning because you can see the chemistry happening rather than reading about it*' and '*I am learning it for myself and can see what's happening*'. This disagrees with some criticisms of inquiry learning; this format provides a rich opportunity to learn, which is clearly appreciated by pupils.

All pupils (bar one) reported that their learning was progressing well, using grade improvements as well as ease of thinking as their measure. This fits with CLT's argument that schemas, '*the basic unit of knowledge*' (Sweller, 1994: 297), are formed as pupils move from novice to expert status, and '*can explain a substantial proportion of our learning-mediated intellectual performance*' (ibid.). The pupil who reported he didn't '*have to think about stuff as much*' any more, was using 'automation', where schemas are automatically recalled from long-term memory but bypass awareness, thus not occupying cognitive capacity that could otherwise be employed more usefully.

Findings from using CASE

Changes in teaching practice, beliefs and attitudes

From the outset, Sam was very keen to purchase and use the Thinking Science scheme. By the end of the research period, interview data revealed a marked increase in the stress he placed on the importance of thinking and collaborative working. Thinking Science is designed to provide a context and scenario in which pupils learn specific cognitive skills, such as thinking, both individually and collaboratively, with careful guidance from a teacher. The changes to Sam's practice demonstrated that he had incorporated some of these key concepts. For instance, in 'concrete preparation', he suggested pupils spent at least five to ten minutes *thinking* about how they'd solve the challenge; during 'cognitive conflict' he urged them to identify the problem, '*think about what we've been doing the last few weeks*', and to share ideas within the group. One of the authors of Thinking Science acknowledges that these two pillars require significant input from the teacher (Adey, 1999), which Sam provided.

During 'construction', he encouraged pupils to slow down, think, plan carefully and work together, urging them to write a method so clear that '*an alien could read and follow it*'. By the end of the year, he issued less guidance, for instance prompting pupils to reach their own conclusions:

> Pupils: '*Sir, is that balanced?*'
>
> Sam: '*Do you think it is?*'
>
> Pupils: '*Yes.*'
>
> Sam: '*Then it is!*'

However, I did not observe Sam teaching his pupils metacognition as the explicit phase set out in the teachers' notes (accompanying each lesson plan). For example, in a lesson on levers, teachers are told that the '*last part of the Notesheet encourages metacognitive reflection on the methods used*' (Adey, Shayer and Yates, 2001: 78) when teachers ask pupils to first individually, then collaboratively, answer the discussion questions. '*The point is to make them think about, and try to put into words, the methods they have been using … Resist the temptation to give them the answer you think they should have written down*' (ibid). At the beginning of the year, Sam argued that his constant prompting and questioning process (which I identified as the processes of cognitive conflict and construction) was how he preferred to address metacognition. Despite being provided with additional guides for metacognition, Sam did not elicit pupils' own thoughts about their thinking and instead gave pupils his own observations of their thinking behaviour at the end of the lesson. Adey describes metacognition as being '*time-consuming and quite difficult to do, and teachers and students need a lot of help and encouragement initially to become more metacognitive in their approach*' (Adey, 1999: 6); this was true in this research. By the end of the research period, I still had not observed the proper teaching of metacognition.

Sam's thoughts about using Thinking Science were mixed. He was pleased with the opportunities the format provided to '*work with the individual groups … to pose questions, to push and stretch them onto the next level of learning*', which teaching a conventional lesson did not permit to the same extent. He also liked the emphasis on getting pupils '*to think for themselves*' because, having been taught the theory first, when '*they have to work out a solution to a problem themselves … it sticks much better*' (although he argued that his own teaching shared this concept: it was '*the same sort of thing that we do here anyway*').

However, he had some criticisms: he found it '*difficult to get hold of the equipment*' and said that if he had the time he would prefer to re-write the lesson as the '*layout was difficult to teach from … It is difficult to plan the lesson until you read it through*'. For the higher ability students he would also have liked some harder extension activities. Sam's greatest problem with Thinking Science was that he would have preferred the topic to contribute to pupils' learning of a specific curriculum. However, this disappointment is perhaps indicative of his misconception of Thinking Science's aim: it is a programme of guided inquiry, designed to run *parallel* to existing curricula, whose lessons are not designed to teach scientific knowledge, but instead provide a practical context in which pupils learn to develop specific cognitive competencies.

For CASE to be successful, as the published research states, it requires a lengthy time frame and substantial input from teachers: each stage must be carefully constructed and led by the teacher, who frames and provides the learning experience. There are several intervention programmes that can be described as fostering '*cognitive acceleration*' and '*none could be regarded as a quick fix*' (Adey and Shayer, 2011: 1).

CASE for pupils

What was the pupils' experience of Thinking Science? Feedback from the lower ability group was more positive: they said they learned better through '*actually doing*' the experiment: '*you don't really understand it unless you actually do it*'. However, all students said they would like to be taught these sorts of lessons more frequently. The higher ability group found the lesson '*very easy*', '*too formal*', '*a bit repetitive*' and '*less flowing*' than their normal lessons. They found the practice questions '*boring*' and were mixed in their opinion of whether they would like to continue with the approach: one respondent preferred Sam's '*normal lessons*', though others said it depended on the topic.

Overall, Sam said he would prefer to teach lessons in his own way, which allows for differentiation, which in Thinking Science he said '*there can't be*'. That said, he would continue to use the CASE approach but only sporadically and where the investigation content fitted his curriculum specification. He said he would include his own extension activities for the upper ability group. He thought it was appropriate for a lower ability class, as it '*cemented their learning as they went. It was relevant*'.

Conclusion

In this case study, it would seem that for either approach to be successful, a proper period of teacher training is required. I spent quite some time both formulating the CLT 'checklist' (Table 1) and ensuring Emma understood each of the principles. It is hoped that the inclusion of this checklist is of use to other science teachers interested in incorporating CLT in their teaching practice. If Sam had received adequate INSET in using CASE, I believe both his delivery and experience of the approach (and his pupils') would have been more positive and ultimately more beneficial. Part 2 will examine two different teaching approaches that incorporate educational neuroscience into their pedagogy: *The Brain-Targeted Teaching Model* (Hardiman, 2012), and *Research-Based Strategies to Ignite Student Learning* (Willis, 2006).

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Rebecca Torrance Jenkins is the lead researcher for the NeuroFiles Education project, which delivers INSET to teachers in using reliable research findings from cognitive psychology and educational neuroscience in the classroom. Email: Rebecca@unlikeminds.co.uk