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JOURNAL OF THE CHARTERED COLLEGE OF TEACHING

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What is the best way to motivate students in your subject?

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Motivation is a complicated beast. Traditionally broken into intrinsic and extrinsic types, students may be motivated by a whole host of competing and intertwined factors. The academic literature varies widely on these definitional terms and how they are measured (Garon-Carier, 2015; see also Didau and Rose, 2016). This is further confounded by a gap between what people believe and what they actually do. For example, a recent and ongoing study into student attitudes to science education found that many students think that science is important and valuable, but do not wish to study it themselves (DeWitt, 2017).

Schools and teachers insert themselves into this cacophonous mix with often confusing and unpredictable results. For instance, a recent large-scale study of attendance interventions found that in schools where students were awarded for 100 per cent attendance, the attendance actually worsened over time. The researchers posit that social pressures (nobody wants to be 'that' student) can affect student motivation to attend. Furthermore, by rewarding 100 per cent, the schools were potentially signalling to students that actually less than 100 per cent was expected, and 100 per cent was above expected, worsening student motivation to attend (Robinson et al., 2018).

In curricular studies, some urge that content should be tailored to the students'

lived experiences in order to boost motivation. However, such a position can betray the 'power' of our subjects, limiting students and failing to open their minds to broader horizons and cultural treasures (Young, 2018). Additionally, such ideas can be difficult to implement – students have a curriculum to follow, and lived experiences aren't always going to be relevant.

An interesting avenue of pursuit relates to the relationship of student ability to long-term motivation. Ryan and Deci's seminal research into Self-Determination Theory (Ryan and Deci, 2000) argues that a vital component of individual motivation is competence. For example, giving people encouraging feedback on their performance increases their motivation: the experience of competence, of being good at something, boosts motivation. Garon-Carier et al. (2015) devised an experiment to test this idea. Defining intrinsic motivation in mathematics as engagement and interest in that subject, they found that motivation at the age of seven was no predictor of performance in mathematics some years later. However, performance at the age of seven *did* predict motivation some years later. Noting dissenting evidence, the researchers concluded that student performance – or competence – strongly affects whether or not they find interest in mathematics in the years to come.

Recently replicated (Nuutila et. al, 2018), this experiment suggests that teachers and schools should be aware that one of the most powerful ways to ensure students become motivated in their subjects is through improving their competence in that subject. As such, it may be more important for teachers to think about the best techniques to improve student performance, rather than techniques to increase their short-term engagement or interest.

An interesting case for discussion could be the role of 'drill', or extensive independent practice. Often derided as 'drill and kill' techniques (see Little, 2016), extensive silent, independent practice can be considered boring and demotivating and substituted for 'engaging' or 'fun' activities. This jars with the evidence base, which generally supports extensive individual practice (Willingham, 2010).

One of the most powerful ways to ensure students become motivated in their subjects is through improving their competence in that subject

Arguing for an appropriation of the phrase 'to drill and thrill', maths teacher Dani Quinn (2017) argues that extensive and carefully designed drill can lead students to feel a sense of success. An interesting comparison here is retrieval practice. It is well known that low-stakes quizzing is a highly effective tool for leveraging long-term memory (Firth et al., 2017), but it is worth noting that in the seminal studies on the topic, participants who undertook retrieval practice actually reported lower confidence in their abilities than those who undertook less effective memory activities, such as rereading or highlighting (Roediger and Butler, 2011). In the short term, challenging activities like retrieval practice can leave students feeling demotivated, or lacking in 'competence'. In the long term, however, such activities are far more likely to bring improved student performance and, with it, a sense of competence and motivation.

The flip side of this is also true. Nuthall's research (2007) revealed that students are most engaged when involved in work that carries minimal cognitive demand. Many activities touted as 'fun and engaging' do not adequately challenge students. As such, activities that appear beneficial in the short term are perhaps less so in the long term, and ones that appear ineffective in the short term may be highly effective in the long term.

In summary, motivation remains a complicated beast. But teachers should know that the day-to-day cycle of expert teaching – explain, practice, review – is a potential winner for building long-term interest and motivation.

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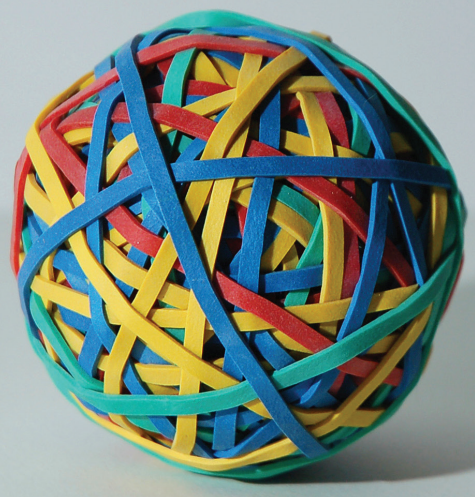

Learning to learn: Using evidence to enhance knowledge retention and improve outcomes

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Like all secondary schools nationwide, we awaited the unveiling of the new linear GCSE and A-level qualifications with a mixture of emotions. Whilst looking forward to updating the curriculum, we were very alert to the challenges that they promised in terms of increased content and rigour, and the challenges for students as they would need to revise a much greater quantity of material for one exam season. We needed to look very carefully at how we empowered students to successfully revise material so that they could retain what they had learned in lessons throughout their new courses. This has coincided with our drive to embed evidence-informed teaching and learning across the school, and so it was logical to look in depth at evidence in the area of knowledge retention. Key concepts that we have found particularly helpful are summarised below, and our focus on these is explained in more detail in the extended online version of this article:

- **Cognitive Load Theory:** To maximise the chance of learning new material, students' knowledge of past topics should be committed to their long-term memory so they don't need to use precious working memory capacity considering them; they can just recall and use them whenever needed (Chandler and Sweller, 2009).
- **Spacing and interleaving:** Spacing and interleaving involve students spreading out their revision over a long period of time and revising several topics concurrently, rather than revising one topic at a time, and have been found to be a more effective approach than cramming (Roediger and Pyc, 2012; Rohrer, 2012).
- **Elaboration and retrieval practice:** Passive revision activities such as rereading and highlighting have been found to be less effective than those that require more thinking (Dunlosky, 2013); elaboration is a revision technique that involves students asking questions about the topic they're studying and making connections with other topics, whilst retrieval practice involves deliberately recalling information, for example in the form of a quiz.

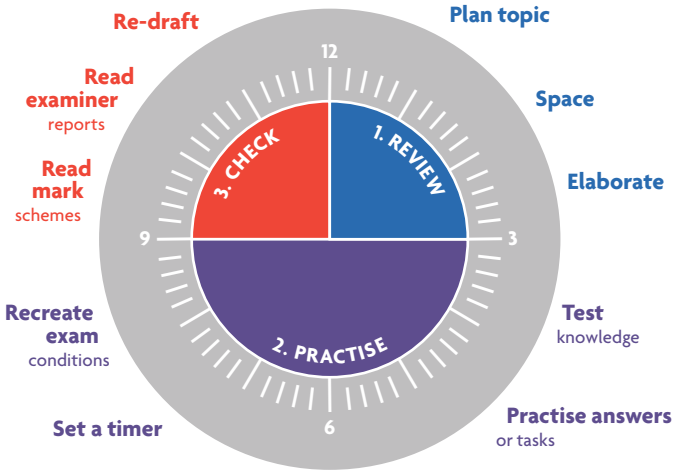
These approaches have been used by individual teachers and departments to support students in organising and carrying out revision, and were seen to be making a positive difference to the knowledge retention of students in exam classes. However, there was a need to embed key messages and strategies across all departments and empower students and parents to understand the evidence and use the suggested strategies. With cramming and highlighting well established in many students' revision routines, this was going to be a challenge. The Memory Clock was developed to help with this wider level of communication and understanding.

Translating theory into practice: The Memory Clock

The idea is captured in Figure 1 and

illustrates how a student could spend an hour of their time when revising (and could be applied to any time period). It aims to highlight the fact that more than 'reviewing' is needed if students are to have the best chance of committing their subjects to memory. Hence, we split our clock into three parts: reviewing, practising and checking activities, which aimed to translate the evidence about spacing, interleaving, elaborating and retrieval practice into a coherent approach (**Figure 1**).

FIGURE 1:
THE MEMORY CLOCK



The first part of the clock focuses on the process of reviewing what needs to be learned. Planning is important to ensure that students have time to cover all topics, and this includes the consideration of spacing out and interleaving revision, rather than mass-revising topics. Communicating the importance of elaborative techniques rather than passive activities such as highlighting was critical in our context, given how many of our students were content to simply reread and highlight notes. We deliberately made this section of the clock short – 15 minutes out of a one-hour period as a guide – as we had observed students revising by only reviewing the material to be learned, rather than moving on to test themselves.

We termed the next phase of the Memory Clock 'practise', which covers low-stakes quizzes and self-testing using cue cards through to the completion of practice exam questions. Testing oneself can be an uncomfortable experience; the feeling of not knowing something immediately can be demoralising. However, what we know from the evidence is that testing – i.e. engaging in retrieval practice – actually supports learning and does so more effectively than most other techniques. As such, we devoted the majority of our Memory Clock to this in order to underscore its importance to our students.

Finally, we prompted students to check their work. The checking stage highlights the need to check the correct answers after testing oneself, which supports learning and identifies mistakes or misconceptions that, if unchecked, could set in (McConnell and Hunt, 2007).

Evaluating the impact

The Memory Clock has been used across most subjects and has been communicated to all students in Years 10 to 13 since 2016/17. Multiple specific subject example models of the memory have been developed by teachers to help students to pick out appropriate activities for each section. Changes in student behaviour are evident. Students have been engaging in revision activities earlier in the school year and are more regularly seen writing out flashcards rather than relying on their highlighters. Furthermore, feedback from student surveys indicates a growing awareness and use of more effective study activities.

Despite excellent exam results in the summer of 2017, where our students achieved levels of progress unmatched by previous cohorts, we're keen to evaluate the effect of the Memory Clock more rigorously. A member of our school's Professional Learning team has successfully applied to carry out a school-based randomised control trial (RCT) with the Educational Development Trust and the Wellcome Trust. The outcomes of this trial will enable us to consider the efficacy of how we have tried to translate the research on effective revision into a tangible model for students.

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Six ways visuals help learning

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This article is based on articles originally published on https://teachinghow2s.com/

Whenever I talk about the power of visuals, I am very keen for the audience to understand I am not referring to particular people, or to the myth of 'visual learners'. However, we now know from research more about how learning occurs, so we can identify specific ways in which visuals support psychological processes. In this article, I reflect on six ideas, many of which are drawn from a 500-page tome on cognitive psychology research called *Graphics for Learning*, by Ruth Colvin Clark and Chopeta Lyons. Clark has worked with John Sweller and Richard Mayer.

1: Visuals support attention

When visuals are not merely decorative or entertaining, they can be used to bring essential information to the fore, for example through visuals such as numbering and arrows, and to draw attention to important elements. This can help avoid the burden of 'split' or 'divided attention'; when text is far away from the visual, or vice versa, the viewer has to expend considerable mental energy in keeping one in mind while attending to the other, increasing cognitive load.

2: Visuals help activate or build prior knowledge

By providing a visual overview of the process, visuals help trigger recognition and anticipate future content. This merging of past and future imagery helps connect to prior learning and assimilate future information.

3: Visuals help minimise cognitive load

Cognitive load is when working memory is overloaded and cannot process any more incoming information (Sweller, 1988). For this reason, photographs and videos can often be counter-productive, and simple line drawings are superior in conveying precise information. Background, or irrelevant detail, can distract, confuse or overwhelm the viewer.

Additionally, some people are tempted to use what are termed decorative visuals, such as clip art, in an attempt to seduce students into taking an interest in the topic at hand. This, too, is counter-productive. It diverts attention away from the lesson's aims and, as a consequence, confuses and overloads.

4: Visuals help build mental models

Well-designed visuals help the viewer construct new memories in their long-term storage, supporting a deeper understanding of the concepts and procedures involved. By locating all the elements on one page — viewed in one go — visuals present a coherent image that is more easily assimilated and stored away for future reference.

5: Visuals help support transfer of learning

The simpler the visual model, the easier it is to retain it in memory for transfer into practice. By focusing solely on those aspects that are directly relevant, the visual model helps the viewer identify key components necessary for deeper understanding.

6: Visuals make use of dual coding

The idea of 'dual coding' theory (Paivio, 1986) is that we can use our visual and auditory channels simultaneously and, significantly, separately. This means that we can absorb more information than is normally considered possible– we avoid the dreaded cognitive load.

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Taking curriculum seriously

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Curriculum is all about power. Decisions about what knowledge to teach are an exercise of power and therefore a weighty ethical responsibility. What we choose to teach confers or denies power. To say that pupils should learn 'the best that has been thought and said' is never adequate. Start the conversation, and questions abound: 'Whose knowledge?'; 'Who decides on "best"?'.

Such questions reflect concern about whether schooling reproduces inequalities or interrupts them. Such questions matter. But reducing knowledge to voice will not get us far either. The contentious questions – Which works of literature? Which historical stories? Which art? – cannot be resolved by some optimal blend of diversity, some nirvana of neutrality, as though distribution across the sources of knowledge or types of knower will settle things. No matter how redemptive of former injustice, no holy grail of content selection will be reached.

Nor does adding in preparation for the 21st century help. How can we decide what is relevant to the ever-shifting 'now'? Worse, relevance quickly merges ›

with *perceptions* of relevance and, before we know it, content is chosen for being engaging or deemed 'relevant' by the pupil. Then we have completely lost our moorings. At that point, we lose touch with the duty of including the next generation in a shared language of abstract concepts, in common tools for precise thought, in the possibility of objective knowledge underlying them and in the possibility of citizens appraising it. These things serve the rationalised sensibility on which participation in a democratic society depends.

Appeal to knowledge *and* skills is no corrective either. These terms invoke such diverse assumptions that discussions end up at cross purposes. And to suggest that knowledge is less important than skills is to ignore the way in which our knowledge changes us, including our curiosity and capacity for new knowledge.

As educators, we need something more coherent concerning the character of knowledge – its structure, its origin, its status as a set of truth claims (such as their revisability) and the relationship of teachers and pupils to that knowledge. How, how far and when can teachers or pupils participate in challenging or reaching those truth claims? In which subjects and under what circumstances must they just accept them (for now) as givens?

How can a senior school leader tackle these questions? School leaders need practical solutions; few have time to swallow philosophical tomes. Yet to shy away from big ideas is always a false saving. And intellectual resources exist that are rigorous, accessible and useful. First, we have longstanding traditions of practice and debate within subject communities concerning ways of teaching the structure, status and origin of knowledge. Second, a relatively recent research programme arising from the sociology of knowledge advances the idea of 'powerful knowledge'. In this article, I will reflect briefly on just one theme emerging from the first, which is further illuminated by the second, namely the curricular distinction between substantive and disciplinary knowledge.

Substantive and disciplinary knowledge

Substantive knowledge is the content that teachers teach as established fact – whether common convention, concept or warranted account of reality. You might want pupils to know of crotchets, percentages, the Treaty of Waitangi, Debussy or prokaryotic cells. In calling this 'substantive', we are treating the material presented as givens.

Disciplinary knowledge, by contrast, is a curricular term for what pupils learn about how that knowledge was established, its degree of certainty and how it continues to be revised by scholars, artists or professional practice. It is that part of the subject where pupils understand each discipline as a tradition of enquiry with its own distinctive pursuit of truth. For each subject is just that: a product and an account of an ongoing truth quest, whether through empirical testing in science, argumentation in philosophy/history, logic in mathematics or beauty in the arts. It describes that part of the curriculum where pupils learn about the conditions under which valid claims can be made, and associated conventions such as what constitutes evidence or argument in that subject.

In those subjects where content choices are potentially infinite and selections must be made, it is through due attention to the disciplinary dimension that pupils know that *what I teach is not all that there is*. In those subjects where truth is sought through argumentation, pupils learn that even the selection and juxtaposition of two facts in a narrative amount to an interpretation, and that interpretation can be conducted responsibly or irresponsibly, but never definitively. A successful history, geography, RE or literature curriculum, in which the disciplinary was visible, will leave pupils absolutely clear that *even the curriculum itself*, as they received it, was one such selection, and must not be confused with the whole domain.

This substantive–disciplinary distinction works to differing extents and in very different ways across subjects. The disciplinary dimension is barely relevant, for example, in school-level modern languages. Moreover, *how* it gains expression in a school curriculum varies widely. In history, pupils encounter historical scholarship in order to learn how historians participate in a social process of claim and counter-claim. But they can't read scholarship without being drawn into the argument themselves. The date of the Treaty of Versailles is a given. Many events before and after the Treaty of Versailles are givens. But attributions of cause, consequence or significance to the Treaty of Versailles are *not* givens. The humblest of Year 7 history essays is elementary training in argumentation and produces legitimately different conclusions. Moreover, teacher-led, subject-specific research traditions have explored multiple ways of doing

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this well by blending secure substantive with rich disciplinary knowledge so as to refine pupils' appreciation and practice of historical argument (e.g. Foster, 2013).

Is it the same in science? Not quite. The substantive and disciplinary distinction definitely holds. Pupils study scientific methods, understand degrees of certainty, conduct investigations. But in terms of pupils' relationship to those processes and conclusions, there are differences. At school level, conclusions are not normally 'up for grabs' by pupils in quite the way they are in philosophy, literature or history, where argumentation itself is the method. In other words, each school subject stands in a slightly different temporal relationship to its real-world cognate of scholarly and professional knowledge production.

Therefore, when schools talk about pupils 'being' artists, historians or scientists, they are rarely talking about the same thing across subjects. In some subjects, we see frequent knowledge production processes (composing and creating; arguing and judging). In others, even those full of practising and doing within subject skills, the balance tilts towards knowledge reproduction, with less open-ended interpretation (a reason to avoid conflating 'disciplinary' with 'skills'). This doesn't mean that disciplinary knowledge is less important where less is 'up for grabs'. It may just mean that pupils (for now) are learning more about how *others* have established truth claims. Even for a textbook or teacher to state, '*Scholars are unsure* whether trade in seventh-century Arabia...' is to show disciplinary attentiveness by modelling responsible claims.

All this matters in whole-school leadership. 'Substantive' and 'disciplinary' are illuminating categories not only for understanding curriculum but also for grasping the implications of curriculum for teaching and assessment. Regarding teaching, they help senior leaders to interpret teaching activities in the light of an object. Before one can apply research into the efficacy of (say) pair/group discussion, one needs to establish *what* is being taught. Failure to do this has caused untold problems. A world of difference exists between a paired discussion designed to practise a facet of open argument derived from a particular discipline and a paired discussion designed for learning substantive content. In one, the dialogue teaches a disciplinary process; in the other, the rationale is constructivist pedagogy. They cannot be appraised in the same way. Regarding assessment, an understanding of substantive and disciplinary would have seen senior leaders questioning the use of level descriptions for formative assessment years earlier than actually happened. Each subject has its own pattern and interplay between learning substantive content and engaging with its origins or processes. The practice of treating *progress* as mini-versions of level descriptions and GCSE mark schemes has dangerously distorted subject structures and journeys.

The expression 'knowledge-rich' curriculum is normally associated only with substantive knowledge. This is understandable given that we're emerging from an era in which mastering content was sidelined, even demonised, and given the attention now paid to research

on the relationship between academic content knowledge and reading, on the vocabulary gap between advantaged and disadvantaged and on the role of knowledge in making subsequent learning possible (Willingham, 2017). But we cannot neglect the disciplinary dimension. This is achievable even in the primary phase. Our Year 4 pupils' questions show that they are fascinated by Mendeleev's cleverness in making the periodic table open and revisable, by van Leeuwenhoek's worries about the Royal Society taking his microscope seriously, by the questions that geographers ask about borders and boundaries.

Powerful knowledge

The categories 'substantive' and 'disciplinary' are merely one cross-section of useful curriculum analysis but they are foundational. Their significance is further illuminated by a body of research within the sociology of knowledge that tackles education's knowledge question within a progressive agenda for social justice (Rata, 2016; Young, 2008). Associated with the concept of 'powerful knowledge', these theorists challenge the view that academic knowledge necessarily perpetuates disadvantage by remaining the preserve of the powerful forces that created it. Drawing on Durkheim, they argue that knowledge developed by academics in intellectual communities becomes independent of those socio-historical origins through its abstract and generalising tendencies. Because this specialised knowledge is not acquired or produced informally in everyday experience, entitlement to it through curriculum is vital (Young and Muller, 2016).

Not only does this knowledge offer the language of abstract concepts, but these precise concepts also become tools

Powerful knowledge theorists emphasise that specialised knowledge is emergent, provisional and revisable through continuing social processes such as scholarly research and critique

with which to imagine change. They enable humans to theorise possibility and think the un-thought (Wheelahan, 2010). To achieve this, a curriculum must enact processes of 'epistemic ascent' (Winch, 2013), by which concepts already understood by students are brought into new relations of abstraction and generality, giving the student yet more power to challenge, rethink and create. McPhail (2014) illustrates this with music. He explains how without epistemic understanding, pupils are restricted to subjective experience of music. Discussing the complex relationships between music's subjective and objective dimensions, McPhail shows how teachers can integrate students' ownership of music's affective power with access to knowledge fundamental to the conversations of the discipline.

While collaborating in building a trust-wide, knowledge-rich curriculum, we have found it useful to reflect on this body of work, not only regarding the power inherent in the abstractions of substantive knowledge, but also regarding each subject's disciplinary dimension. Powerful knowledge theorists emphasise that specialised knowledge is emergent, provisional and revisable through continuing social processes such as scholarly research and critique. For pupils to learn how knowledge is formed and changed distinguishes a knowledge-rich curriculum grounded in 'powerful knowledge' from one merely ossifying a canon. In a stark prediction of three futures, Young and Muller (2016) contrast a Future 1 in which knowledge is fixed and tied to the social context that produced it, and a Future 3 whose radical potential harnesses the fertile, generative qualities of knowledge to give all citizens access to intellectual tools for rational change.

This article scratches the surface of debates that school and system leaders cannot ignore. Given its implications for democracy, curriculum is a serious business. We must engage with its provenance and properties.

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What is a 'knowledge-rich' curriculum?

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In the last few years, there has been a fascinating debate developing around the concept of a 'knowledge-rich curriculum'. Sometimes this is referred to as knowledge-led or knowledge-based. The debate has been informed by discussions from cognitive science, such as the role of knowledge in underpinning reading and understanding (e.g. Willingham, 2010). It has also been informed by a values-led philosophy based on empowerment through teaching 'powerful knowledge' (e.g. Young and Muller, 2013). Along with plenty of others, my initial reaction was to reject the idea that a curriculum could be 'knowledge-rich'; I saw it as a kind of hubristic rebranding of regular good practice. As a science teacher, I've always felt that my curriculum was packed with knowledge and, without question, I've seen numerous cohorts sit lots of GCSE exams, year after year, each requiring significant knowledge. However, I'm increasingly convinced that a knowledge-rich curriculum is actually an important concept that we ought to embrace.

From my experience working with a range of schools in varying circumstances over the last few years, I would say that not only is this approach often different to the default practice, but it also offers a secure route to the higher standards that we're continually seeking. Even if it's not new, at the very least it represents a shift in emphasis with multiple benefits.

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What is a knowledge-rich curriculum in principle?

Based on my reading of the debate, I would suggest that there are four components:

Knowledge provides a driving, underpinning philosophy

The *grammar* of each subject is given high status. Here, 'grammar' relates to the concepts explored by Martin Robinson in *Trivium 21c* (Robinson, 2013) – the knowledge content and traditions within subject disciplines. In a knowledge-rich curriculum, the specifics of what we want students to learn matter and subject traditions are respected. Skills and understanding are seen as forms of knowledge and it is understood that there are no real generic skills that can be taught outside of specific knowledge domains. Acquiring powerful knowledge is seen as an end itself; there is a belief that we are all empowered through knowing things and that this cannot be left to chance. There is also a sense that the creative, 'rounded and grounded' citizens we all want to develop – with a host of strong character traits – will emerge through being immersed in a knowledge-rich curriculum.

The knowledge content is specified in detail

Units of work are supported by statements that detail the knowledge to be learned – something that can be written down. We do not merely want to 'do the Romans'; we want children to gain some specified knowledge of the Romans as well as a broad overview. We want children to know specific things about plants and about the Amazon Rainforest, WWII, Romeo and Juliet and climate change. We want children to have more than a general sense of a topic through vaguely remembered *knowledge encounters*; in addition to a range of memorable, enriching experiences from which important tacit knowledge is gained, we want them to amass a body of specific declarative and procedural knowledge – not ad hoc but planned. This runs through every phase of school; units of work are not defined by headings but by details: e.g. beyond the 'environmental impact of fossil fuels', the specific impacts are detailed.

Knowledge is taught to be remembered, not merely encountered

A good knowledge-rich curriculum embraces ideas from cognitive science about memory, forgetting and the power of retrieval practice. Our curriculum is not simply a set of encounters from which children form ad hoc memories; it is designed to be remembered in detail – to be stored in our students' long-term memories so that they can later build on it, forming ever wider and deeper schemas. This requires approaches to curriculum planning and delivery that build in spaced retrieval practice, formative low-stakes testing and plenty of repeated practice for automaticity and fluency.

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Knowledge is sequenced and mapped deliberately and coherently

Beyond the knowledge specified for each unit, a knowledge-rich curriculum is planned vertically and horizontally, giving thought to the optimum knowledge sequence for building secure schemas - a kinetic model for materials; a timeline for historical events; a sense of the canon in literature; a sense of place; a framework for understanding cultural diversity and human development and evolution. Attention is also given to known misconceptions, and there is an understanding of the instructional tools needed to move students from novice to expert in various subject domains.

Importantly, these four elements lead to a curriculum far more expansive than a reductive set of knowledge statements. A knowledge-rich curriculum is packed with experiences and is driven by a strong set of values about what matters; it has soul, moral purpose, humanity.

What is a knowledge-rich curriculum in practice?

The best way to attack this is through some examples:

Exhibit A: The Romans

Imagine Year 8s looking back to when they 'did the Romans' in Year 4. What would we want them to remember? They might recall their museum trip, something about togas and what Roman soldiers looked like. They might have a general sense that Romans had an empire a long time ago. In a knowledge-rich curriculum they would remember all of this but would also be expected to know who Julius Caesar was, the terms *empire, emperor, centurion, amphitheatre, aqueduct;* dates placing the Romans in time in relation to Jesus and 1066 and be able to identify key Roman sites in the UK and Europe. This would be part of a long-term plan ensuring students return to Roman history beyond Year 4 such that their knowledge would be built on, not left behind.

Exhibit B: Parliament Hill Science

At this Camden school, the science department has developed a superb set of study guides in booklet form. More detailed than a knowledge organiser but stripped down from what might be in a text-book, the booklets contain embedded quizzes used to test them on their knowledge. They are seen in advance so that students can learn the form in which knowledge is sometimes expressed. It guides their learning. Students are asked to learn the material after being taught it and then take the quizzes without any study aids. Their theory is that, if students can't get the simple factual recall questions right, they have no chance of then getting the 'application to new contexts' questions right. This embedded quizzing builds lower attaining students' confidence, knowledge and study skills and has paid dividends.

Exhibit C: Trial by Ordeal

Teaching the GCSE History theme study on Crime and Punishment, you might show the relevant BBC Bitesize video: https://www.bbc.com/education/clips/zrtk2hv. It's a colourful story full of examples, facts, concepts and gory details, feeding wonderful engaging discussions. But, days and weeks later, what would students remember? For certain, the weakest students will have the worst notes and, in all likelihood, the lowest level of recall. It's not enough. In a knowledge-rich approach, we don't leave this to chance. Alongside the discussion, we make the note-making absolutely explicit. *These are the key facts about trial by ordeal that everyone must know*. You control it; you are precise about it.

Exhibit D: Sequenced knowledge of Motors.

If I teach motors I want to make sure that the knowledge builds securely. Early on at KS3, through demonstrations and practical tasks, I want students to build their tacit experiential knowledge of the key phenomena: magnetic attraction and repulsion, the idea of 'field strength'; forces; current – each with direction and magnitude; the idea that phenomena interact. We would focus on changes of direction and the simple but magnificent awe and wonder that motors work at all in our universe. Later, as part of a spiral curriculum, avoiding cognitive overload and building on prior knowledge, I need students to understand and use the formula F = BIL and Fleming's left hand rule. I need them to learn the equation by heart and practise using it and manipulating it. I build the sequence carefully, deliberately with a focus on practice, recall and schema-building.

Is this new? To many teachers and in many schools, I think it is – especially once the cognitive science combines with the idea of subject grammar. It's way beyond reductive ideas about rote learning and regurgitating facts for no purpose. It's about ensuring that all students always have a secure knowledge platform, allowing them to reach the next level. In truth, it doesn't really matter whether we did this before... some of us will have, some won't, and that will depend on context, subject, phase and which decade we started teaching in. The point is that we should all be doing it now. It's actually rather exciting!

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The full-length online version of this article includes a list of blogs for further reference. This can be accessed at: impact.chartered.college.

Making sense of metacognition

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Amy's geography teacher has asked the class to prepare a short presentation about rainforest ecosystems. To plan this, Amy reflects on how she learned best on the last topic – using the school textbooks – and decides to read the relevant chapter before drafting her presentation points. However, when reading it, she decides that the chapter isn't explained clearly enough to improve her understanding. She starts to panic, as she was relying on this.

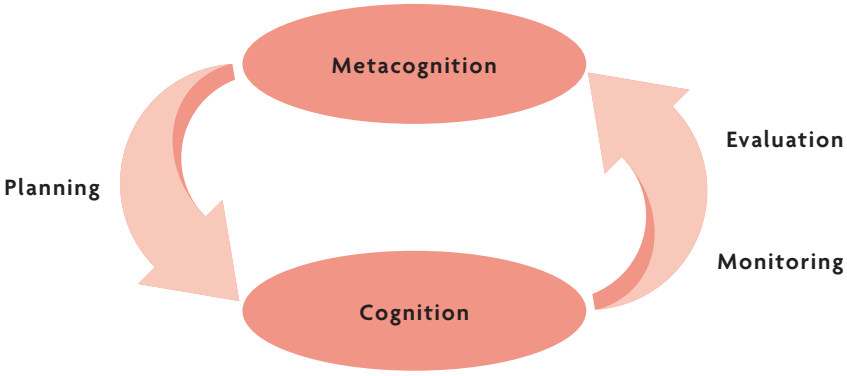
Then Amy remembers a geography website her teacher mentioned. She adapts her strategy and searches the website. This provides a more useful overview, and she uses the information to summarise some interesting facts. She reflects on the experience and decides that next time she will gather a range of resources before starting to research a topic, rather than relying on one source.

This short anecdote about Amy provides a familiar scene of schoolchildren grappling with their homework each evening in homes across England. When you dig beneath the surface of Amy's actions, you begin to consider how she thinks hard about her learning. Here, she is proving to be a successful learner, having internalised some effective strategies for *planning*, *monitoring* and *evaluating* her geography learning.

Most often, such learner behaviours are hidden in plain sight. Students like Amy go on to prove a success in geography and beyond, whereas some of Amy's peers simply flounder and fall away over time. Some teachers cultivate and nurture the metacognitive strategies used by Amy, explicitly naming them, guiding practice and promoting them daily, but many teachers do not do this so explicitly, so pupils may not develop the most effective strategies over time.

It becomes useful then to better define the key characteristics of effective learners, using well understood terms to underpin our practice in schools. The Amy example is a concrete example of **metacognition and self-regulation**. The Sutton Trust-Education Endowment Foundation's Teaching and Learning Toolkit (Education Endowment Foundation, 2018) suggests that it is one of the most effective approaches for improving pupils' attainment outcomes. So, how can teachers be helped to understand the terms? And how can the skills be developed and supported in the classroom?

FIGURE 1:
VISUAL MODEL OF COGNITIVE PROCESSES



Guiding teacher understanding of metacognition

Ask a staffroom full of teachers for a definition of metacognition and you will likely receive the familiar stock answer: 'thinking about thinking'. The problem here is that such a definition is vague and slippery. It certainly does not help a Year 5 teacher on a wet Wednesday afternoon, or a Year 11 maths teacher tackling trigonometry after break-time! Other definitions, such as 'learning to learn', are equally vague and can actually promote the misconception that metacognition is a generic skill that is not bound to subject knowledge – that we are not actually thinking about something.

There is a wealth of evidence to better understand metacognition so that teachers of every key phase, key stage and subject can support learners like Amy to thrive in and out of the classroom (e.g. Dignath and Büttner, 2008). If we can better define metacognition, we can go on to make it concrete for teachers and pupils, whilst dispelling some common misconceptions about what metacognition is, and what it isn't.

Metacognition is a part of self-regulation: those self-directive processes that direct our learning. As shown in the example of Amy, it requires:

- **Knowledge of yourself as a learner** (such as how Amy considers how she had performed successfully on her previous topic)
- **Knowledge of appropriate strategies** (such as how Amy drafts her presentation points and searches the internet)
- **Knowledge of the task** (such as how Amy knows that such a presentation requires the essential information offered by the textbook).

An effective learner will monitor their knowledge and cognitive processes, and use this understanding to make judgements about how to direct their efforts. Let's take the following example. Try this straightforward mathematics multiplication: 155 x 3. You may find it easy, but you will still draw upon some tried-and-tested strategies based on your maths knowledge, and you will have a good sense of whether your answer is correct. Now, how about 145,343,233 x 3? Here, you need to reflect a little bit more. You may know that you have too limited an array of mathematical strategies for this challenge. You may be rapidly searching for a calculator, at least to check your answer. It is in those moments when you are selecting the best strategy that you are behaving metacognitively.

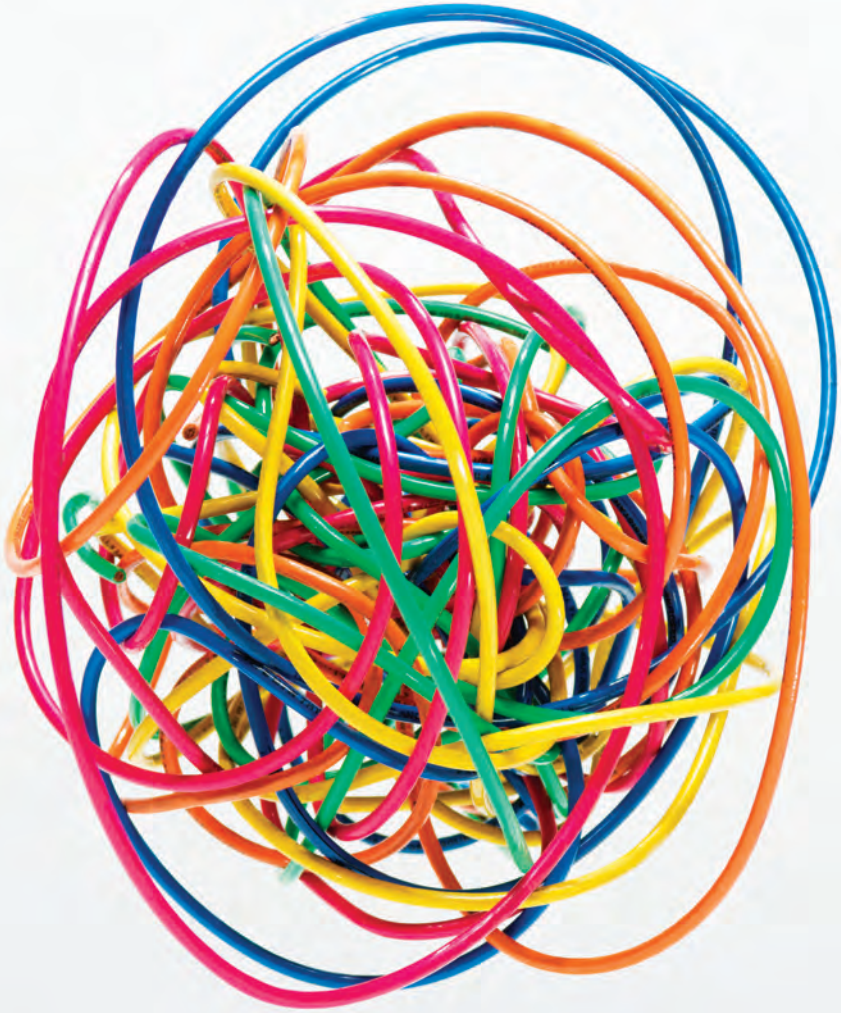
What we learn is that cognitive processes are controlled and adapted constantly. We are always making decisions about our learning in the moment. These decisions happen intuitively but, with explicit teaching and scaffolding, they can be better and more habitually enacted by pupils.

A visual model here is useful, as shown in **Figure 1** (adapted from Nelson and Narens, 1990).

This not a one-off process of discrete steps, but an ongoing cycle. As you progress through the task, you update your metacognitive knowledge (of yourself, your strategies and tasks), as well as updating your subject knowledge (in this example, Amy is learning about rainforest ecosystems, as well as learning about the best research strategies).

The cycle of '**plan, monitor, evaluate**' and the different aspects of metacognitive knowledge (**learner, strategies, task**) are recurrent triplicates that are helpful in making the understanding of metacognition concrete for teachers.

Teachers can then consider these when setting learning tasks and supporting pupils to complete them. In an expert learner (as most teachers are), these processes are unconscious and automatic. In novice learners, however, it can be valuable to make them explicit. For students like Amy, and for teachers, defining and better understanding metacognition can prove a crucial support factor for success in school.



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Dispelling metacognition misconceptions

One of the important ways for teachers to better understand metacognition and to teach pupils such strategies is to first dispel some common misconceptions about metacognition.

Misconception 1: Metacognition is a general skill that should be taught separately from subject knowledge

This is perhaps the most common misconception about metacognition. The clue is in the word: without cognition, there is no metacognition. Contrary to the misconception, metacognition is specific to the task and subject, and stronger where learners have a strong grounding in subject knowledge. It is, for example, very hard to have knowledge about how one can learn, such as through applying different strategies, in a subject without solid knowledge of subject-specific content and skills. For example, Amy must have a sound knowledge of the rainforest and its various levels, alongside the notion of an ecosystem, for her to decide the relevant evidence required from her textbook.

Therefore, teaching and practising metacognitive strategies must be done alongside subject content. Generic 'learning to learn' or 'thinking skills' lessons may be able to impart some useful overarching idea, but pupils can struggle to transfer generic approaches to specific subject domains. Self-regulated learning and metacognition have been found to be quite context-dependent, so how you best plan in Key Stage 2 art may have significant differences to planning strategies in Key Stage 4 maths. This does not, however, mean that metacognitive knowledge and skills will automatically develop through content knowledge teaching.

Misconception 2: Metacognition represents 'higher order' thinking and is therefore more important than mere cognition or subject knowledge

We know that metacognition is the knowledge of cognition and the strategies to regulate and control it. However, it would be a mistake to see metacognition as somehow 'higher order', hierarchically, and therefore more important than cognition (as Bloom's taxonomy is sometimes misinterpreted as being a hierarchy that privileges 'evaluation' over 'knowledge'). As has been pointed out, it is very hard to have knowledge about how competent you are in a given subject domain, or how best you can learn, without solid subject knowledge (Pressley and Harris, 2006).

For example, a student can use metacognitive planning strategies when

Teaching and practising metacognitive strategies must be done alongside subject content

drafting a GCSE essay about Shakespeare. But without knowledge of Shakespeare's plays, language and the relevant social context, the essay will not be successful.

Metacognition and cognition then display a complex interplay as our pupils learn. We should look to develop both concurrently and not create false hierarchies where they do not exist.

Misconception 3: Metacognition is only developed in older pupils

A common misconception with regard to metacognition knowledge and skills is that they are only developed effectively in mature young adults and not young children. We know from research, however, that children as young as three have been able to engage in a wide range of metcognitive and self-regulatory behaviours, such as setting themselves goals and checking their understanging (Whitebread and Coltman, 2010). They also show greater accuracy on tasks that they accept to do than on tasks they don't (Bernard et al., 2015).

There is clear evidence that the level of security and self-knowledge remains rather inaccurate until about eight years of age, with children being overoptimistic about their levels of knowledge (Clark and Dumas, 2016), but the overall trend suggests that forms of metacognition emerge early on in the lifespan. Ultimately, although older children do typically exhibit a broader repertoire of metacognitive strategies, younger children do generally demonstrate metacognitive knowledge, even at a very early age.

Metacognition in the classroom

All pupils develop metacognitive knowledge and skills in their time at school. And yet, some are more adept at doing this than others. They go on to make countless actions and decisions about their learning – many of which the teacher has little control over.

By improving their own understanding, teachers will be better able to support pupils to develop their metacognitive skills and knowledge

Recommendations from the evidence would suggest that teachers can be much more deliberate about teaching metacognitive awareness in the crucible of the classroom. A familiar example is 'shared writing', where the expert teacher (such as Amy's geography teacher) undertakes a written task. As she walks through an explanation of a jungle ecosystem, she verbalises the questions a geographer would ask of themselves, such as *'How many levels are there in the jungle ecosystem?'* and *'How could I organise that clearly in my writing?'*

As well as modelling and scaffolding explicit strategies, cultivating metacognitive talk between students can improve outcomes. For example, the 'dialogic teaching', as devised by Robin Alexander (2017), emphasises dialogue through which pupils learn to reason, discuss, argue and explain. A key element of the dialogic approach is to encourage greater quality of teacher talk, by going beyond the closed *teacher question – pupil response – teacher feedback* sequence. Importantly, in this and other successful interventions, dialogue needs to be purposeful and not just conversation, with teachers using questions to elicit further thought.

What an evidence-based understanding of metacognition offers us is a shared language with which to describe, define and teach effective learning. By improving their own understanding, teachers will be better able to support pupils to develop their metacognitive skills and knowledge. When we train our students to plan, monitor and evaluate, with conscious awareness within a given subject discipline, we offer them the knowledge and strategies to succeed, not only in the classroom but far beyond the school gates too.

This article is based on an EEF-commissioned evidence review examining these questions, drawing upon the expertise of Professor Daniel Muijs and Dr Christian Bokhove. A guidance report on metacognition and self-regulated learning for teachers and leaders was published by the EEF in April.

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Subject scholarship as a mechanism for developing trainees' reflective practice and teachers' curricular thinking

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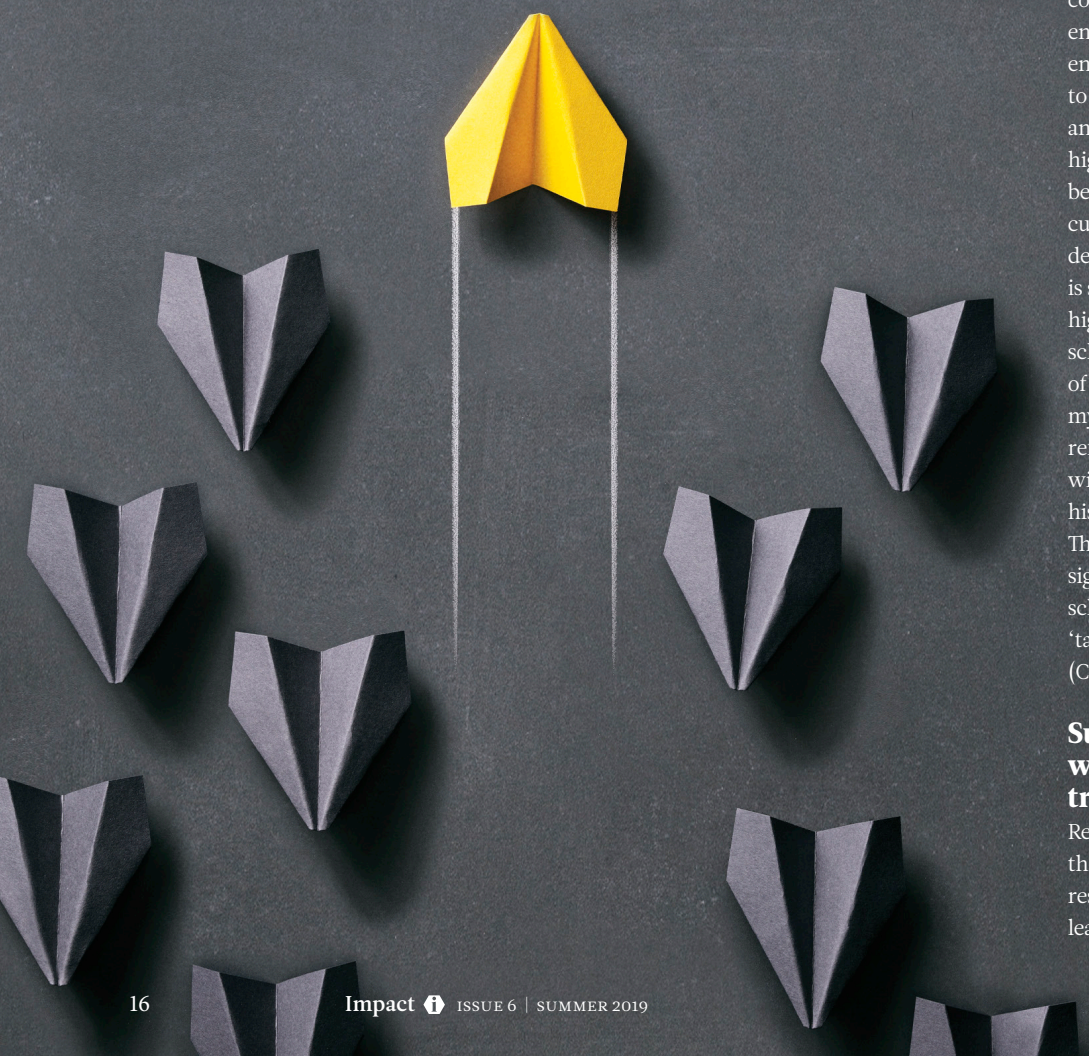

In considering the importance of knowledge and subject-specialist teaching, Lambert (2018) highlights that 'the curriculum: the quality of its contents, its sequencing and its enactment are all curriculum enactment responsibilities that fall to teachers' (p. 363). Therefore, any concern for developing high-quality curriculum cannot be separated from how teachers' curriculum understanding is developed and subject expertise is sustained. In this article, I will highlight the importance of subject scholarship in the mentoring of trainee teachers, drawing on my experience as a mentor and reflecting on the model developed within the University of Cambridge history PGCE (Counsell, 2012). This article seeks to illuminate the significance of subject-specific scholarship in the context of 'taking curriculum seriously' (Counsell, 2018a).

Subject scholarship within the mentoring of trainee teachers

Reading about the principles for the usefulness of educational research for trainee teachers' learning (Counsell et al., 2000),

I was particularly interested in Principle 6, which suggests that 'research-based ideas should be recognised as useful by the "community of practice" to which the trainee teachers will belong' (p. 471). Counsell et al. (2000) propose that trainees want to be accepted into the profession and so conform to the established professional culture. Therefore, the value of scholarship is elevated when mentors and other teachers engage with this scholarship in relation to their own practice. Brooks (2011) highlights that it is by focusing on the professional decision-making of teachers during initial teacher education (ITE) that we can effectively bring together theory and practice. Brooks (2017) has also illuminated the need for mentoring practices to be developed in relation to the subject being taught. Influenced by Counsell et al. (2000), I felt that as a mentor I needed to read the same geography education scholarship as my trainees, and that in so doing, this scholarship could be deployed to shape trainees' targets and training activities and invoked through discussions in mentor meetings and dialogue around lesson observations. This is in line with educative mentoring, whereby teachers are positioned as learners (Langdon and Ward, 2015) and both mentors and trainees are able to benefit through professional learning.

Upon reading Counsell (2012), I was intrigued by how a community of mentors placed their subject at the heart of their mentoring practices. This began simply with several readings being shared, and over time developed into fortnightly reading themes that sustained trainees' engagement in scholarship during their school placement. The fortnightly themes required mentors and trainees to read and discuss literature from both history education and history, and enabled them to situate practical discussions within this discourse (Counsell, 2012). Counsell (2012) conducted analysis of eight history trainees' weekly mentoring meetings. This illuminated the importance of how mentors invoked this literature to support their trainees in immediate, practical decision-making in the form of both planning and evaluation. Scholarship provides a strong basis for 'shared discourse for mentoring' (Hobson et al., 2009, p. 212) within this community. This is exemplified in the scholarship of an experienced history teacher, a head of department and a trainee teacher who collectively read history and history education scholarship to address a practical issue of how to enable students to draw together their historical knowledge in relation to an enquiry examining the continuity in the treatment of mental health through time (Murray et al., 2013). In pursuing this through the use of scholarship, it shifted the history teachers' curricular thinking, such that they began to question how to 'represent or theorise continuity in attitude rather than change in method' (Murray et al., 2013, p. 53).

The value of scholarship is elevated when mentors and other teachers engage with this scholarship in relation to their own practice

In my own mentoring practice, I began to more routinely draw on geography education scholarship as a way of guiding the reflective practice of trainees (Brooks, 2017). For example, as a trainee grappled with how place could be conceptualised for students in the geography classroom, I was able to support her to think more deeply about her own practice and to situate this within the scholarship and practice of other geography teachers. Bustin's (2011) scholarship was integral here, because it provided insight into the process by which as a geography teacher he was able to draw on the concept of Thirdspace (Soja, 1996) from academic geography, to enable students to learn about urban social issues with respect for the lived experience of disadvantaged communities.

Geography education scholarship contributing to curricular thinking

Rawding's (2017) chapter in *Debates in Geography Education* draws on two key ideas of the Anthropocene and the global, in proposing a unifying approach towards school geography that emphasises the interconnectedness of human and physical geography. Reading such scholarship within ›

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a community of geography teachers was exciting – it allowed us firstly to think deeply about geography. Secondly, it had the capacity to change the nature of our curriculum thinking. It helped us to look at the geography curriculum more holistically, moving beyond a topic-by-topic approach around curriculum planning to open up a deeper conversation about the manifestation of knowledge over time. Here we were motivated to think more carefully about how and why a certain section of the curriculum serves to prepare students for future content, such that it has a proximal function to make the next stage possible and an ultimate function to do an enduring job (Counsell, 2018b). This allowed us to think about how the interplay between different types of geographical content serve as part of students' wider geography curriculum journey. The notion of the Anthropocene is not something that students would come to grasp in its full complexity within a short sequence of lessons, and so it was fruitful to think about how it would be encountered across different aspects of the geography curriculum. This also gave us a springboard to think about substantive geographical concepts that students would encounter repeatedly, and in doing so how we could use this as an opportunity to ensure that students developed more nuanced meanings of these concepts over time. If scholarship has the power to nurture teachers' curriculum thinking and stimulate curriculum-making in this way, it also has the capacity to enrich the experience of students in the geography classroom.

In the context of changes to the professional landscape, whereby Ofsted (2019) intends to scrutinise curriculum intent, implementation and impact with the introduction of the 'education inspection framework', engaging with geography and geography education scholarship illustrates a mechanism by which subject leaders and teachers are able to engage in meaningful reflection that can develop their curricular thinking.

Conclusion

Ultimately, I hope that this illustrates how the value of geography education scholarship is not necessarily discernible from the scholarship in and of itself, but rather how the merits become apparent when you recognise how it can shape geography teachers' and teacher educators' curricular thinking, serve as a knowledge base for inducting teachers into the geography education community, and provide a foundation for others to continue to strive for a 'deeper understanding of the professional work of geography teachers: to support teachers in "being" geography education professionals' (Brooks, 2012, p. 307).

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The application of spacing and interleaving approaches in the classroom

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Spacing and interleaving approaches have attracted significant interest over the past few years, with research suggesting they have the potential to support both retention and transfer of learning. The small-scale study reported here, in conjunction with a review of the literature, was undertaken to explore the effect of interleaving and spacing in authentic classroom learning of concepts.

An overview of interleaving and spacing

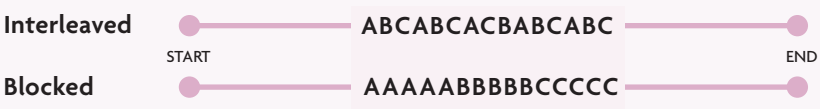
Interleaving refers to the benefits of sequencing learning tasks so that similar items – two examples of the same concept, say – are interspersed with different types of items rather than being consecutive. This results in a more variable and challenging task but is associated with benefits in terms of memory and transfer, which apply to concept learning as well as other domains (Kang, 2016).

Interleaving tends to be contrasted with classroom tasks that are scheduled in blocks of similar items, with the latter termed a 'blocked' arrangement. For example, in **Figure 1**, item 'A' is interleaved with items 'B' and 'C'.

The spacing effect, meanwhile, refers to the benefit of incorporating time delays between learning and practice, leading to improved performance over educationally relevant time periods (Cepeda et al., 2008), compared to 'massed' items, ›

FIGURE 1:
BLOCKED AND INTERLEAVING STUDY SAMPLES

In the 'interleaved' sequence, each instance of item 'A' is surrounded by different items; this contrasts with a 'blocked' presentation, where similar items appear together



where practice sessions occur close together. An interleaved presentation of material is inevitably spaced to some extent, given that sequencing items so that they are non-consecutive leads to a time delay between one example and the next. For example, in **Figure 1**, there are larger gaps between the instances of item 'A' in the interleaving sequence than in the blocked sequence.

However, a key difference between the two effects is that when items are spaced, the gaps between learning and practice needn't include related material. Indeed, the benefits of interleaving seem to depend on the mixing of related items, such as examples from similar categories. Interleaving also seems to be especially effective when differences between items are subtle (Carvalho and Goldstone, 2014). This may be because such scheduling puts different items side by side, improving the perception of differences between them (Kornell and Bjork, 2008). This is known as the discriminative-contrast hypothesis, and is supported by research into interleaving of unrelated categories. One such study (Hausman and Kornell, 2014) interleaved anatomy terms with Indonesian vocabulary and found no benefit.

Birnbaum et al. (2013), meanwhile, presented participants with images of different types of butterfly, either in groups with four different pictures of the same species (blocked) or four pictures of different species (interleaved). Participants were later tested on novel examples, and identified them more accurately following the interleaved study. However, this benefit disappeared if the two types of presentation (blocked versus interleaved) both had their temporal spacing increased, apparently due to this interfering with discriminative contrast (see Figure 2).

Both interleaving and spacing are what Bjork and Bjork (2011) term 'desirable difficulties', i.e. strategies that make learning more difficult, but in a way that is beneficial. They are both widely recommended among those who aim to apply cognitive psychology to education, appearing among the 'Six Strategies for Effective Learning' in the popular Learning Scientists blog (www.learningscientists.org).

The two strategies differ in their primary benefits. The spacing effect boosts memory – practice or restudy of material is more effective if spaced out over time – while interleaving boosts inductive category learning and later transfer. Recent demonstrations of this include the categorisation of chemicals into types (Eglington and Kang, 2017) and the conceptual learning of science categories or examples (e.g. Rawson et al., 2015).

However, there are some caveats. Smith and Scarf (2017) note that for spacing learning across days to be helpful, a minimum initial level of experience is required. Davis et al. (2017) have found that frequent switching between studying and test questions can be detrimental, while Kang (2016) reasons that a hybrid approach can be beneficial, with new learning occurring via blocked practice, and interleaving used in a practice or consolidation phase.

FIGURE 2:
FINDINGS OF BIRNBAUM ET AL. (2013), EXPERIMENT 2

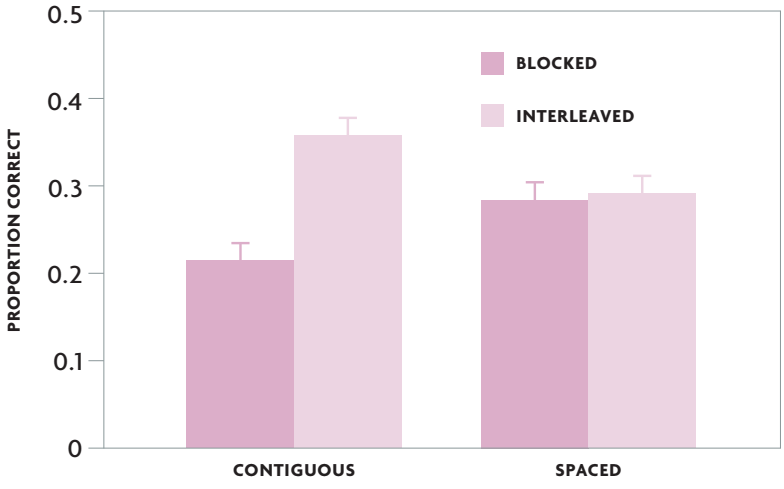


FIGURE 3:
TABLE OF MEAN SCORES

	Spaced (n=15)	Massed (n=16)	Interleaved (n=15)	Blocked (n=16)
Mean	9.45	12.2	10.83	10.87
Standard error	0.59	0.57	0.59	0.57

Research study

To explore the effects of spacing and interleaving in an authentic classroom context, a classroom-based research project was undertaken. An opportunity sample of 31 school pupils between 16 and 17 years of age was used. Data was gathered during an end-of-year taster session, during which pupils sampled several subjects. They were entirely new to the topic being learned.

In order to make the tasks as authentic as possible, all materials were based around a school psychology specification, featuring psychological theories of phobias. The experiment aimed to reproduce the range of activities in a typical school class, and so learners were taught both the concepts (types of phobia) and relevant research evidence.

Tasks were delivered via an online protocol. The target learning material was presented in two main phases. In the first, a research study pertaining to phobias was shown on two screens, one with a description of the study and one with evaluation points, with the latter

either presented immediately (massed condition) or after the second phase (spaced condition). The precise time delay for each participant therefore depended on their reading speed during the second phase (reading 353 words on screen); pilot testing had indicated a delay of two to three minutes.

During the second phase, types of phobia (specific phobia, agoraphobia and social anxiety) were defined, with key diagnostic information given; concepts and information were either presented together (blocked) or mixed with information about different types of phobia on the same screen (interleaved). For example, in the blocked condition, a participant would view three items relating to agoraphobia, while in the interleaved condition they would view a key feature of each of the three types. The online tasks also featured a test, comprising multiple choice questions about the research studies and the categorisation of novel examples of each type of phobia.

Participants sat at individual PCs, and a teacher oversaw the session. After a general briefing, each completed an on-screen consent form, followed by viewing the material presented in an order that depended on allocation to experimental conditions, which was decided via random numbers. As soon as participants had completed the task, the software automatically initiated the test.

Ethics approval followed the school's framework; as a research-focused school, it had set up its own in-school ethics board, with an academic panel providing oversight.

Findings

The mean percentages of correct answers on the end-of-task test for the interleaved and blocked conditions are shown in Figure 3. A between-subjects ANOVA was carried out. This analysis revealed a significant main effect of spacing (performance in the spaced condition being worse than the massed condition, with mean scores of 12.25 vs 9.45, $p = .002$), while interleaving did not have a significant main effect. ›

Importantly, there was also a significant (p = .009) interaction between the two variables (spacing v's interleaving), indicating that interleaving had a mediating or protective effect against the difficulties caused by spacing.

Discussion

The findings demonstrated that spacing had a harmful effect on outcomes in the immediate test, while the main effect of interleaving was neutral. The results fit with the idea that these are 'desirable difficulties', with the potential to impede learning in the short term. Soderstrom and Bjork (2015) describe how such strategies often lead to performance being slower and more error-prone, but improve learning over longer intervals.

Nevertheless, increased errors within a short learning session could suggest inefficiency in the learning process, and raise questions about the use of spacing, in particular with new concept learning. In a related finding, Donovan and Radosevich (1999) found that spacing was not beneficial for complex tasks; complexity interacts with learner experience and, when learning a new concept, complexity for a learner can be high. Such an explanation suggests that desirable difficulties interact with learner skill, as proposed by McDaniel and Butler (2011).

One way to get around short-term difficulties is to utilise a hybrid schedule, with interleaved or spaced practice being utilised subsequent to an initial learning phase. This fits with the recommendation of Rawson and Dunlosky (2011) that learners should first automise recall of concepts, and later retrieve items three times at widely spaced intervals. Interestingly, Yan et al. (2017) found that a blocked-to-interleaved schedule was not superior to pure interleaving, which fits the current findings that interleaving alone did not cause short-term difficulties.

The interesting finding of the significant (p = .009) interaction between the two variables (spacing vs interleaving), indicating that interleaving had a mediating or protective effect against the difficulties caused by spacing, is worthy of further investigation and is discussed in more depth in the online version of this article. On the face of it, this result does not fit well with Birnbaum et al.'s (2013) finding of a negative interaction between spacing and interleaving; however, it is important to note that, unlike in that experiment, the two interventions here were used in different task phases, and spacing therefore didn't prevent discriminative contrast.

Limitations and areas for further research

The present study was limited in terms of its scope and sample. A small number of pupils at the same stage of education were tested; any discussion of the effects of spacing and interleaving must take account of individual learner differences, and future studies should increase sample size and diversity.

As the learners in this study were new to the material being studied, a control group was not deemed necessary, given that prior concept knowledge was assumed to be absent. Future studies could confirm this assumption by presenting the test phase alone to a comparable group of pupils.

The present study focused on a relatively brief set of tasks within a single lesson, and future work could follow learners over a longer period to see how desirable difficulties play out across the learning of a topic. It is also essential to establish the extent to which the negative short-term classroom effects of interleaving and spacing would be counteracted by improved long-term ability to remember and transfer learning.

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