

COGNITIVE SCIENCE APPROACHES IN THE CLASSROOM: A REVIEW OF THE EVIDENCE



Education
Endowment
Foundation

This report summarises the contents of a longer systematic, evidence and practice review produced by a team from the University of Birmingham, England.

We would like to thank all those who have contributed or provided advice in the production of the original review, and this teacher facing summary.

Review team: Dr Thomas Perry, Dr Rosanna Lea, Clara Rübner Jørgensen (University of Birmingham), Prof. Philippa Cordingley (CUREE), Prof. Kimron Shapiro, Prof. Deborah Youdell (University of Birmingham).

Additional support in writing this practitioner summary was provided by Jonathan Kay and Harry Madgwick (EEF).

We would also like to thank the advisory panel who assisted the review team.

Advisory panel: Dr Robin Bevan, Prof. Robert Coe, Dr Iroise Dumontheil, Dr Amy Fancourt, Dr Davinia Fernández-Espejo, Julia Harrington, Dr Niki Kaiser, Mark Stow, Prof. Hillevi Lenz Taguchi, Sonia Thompson, Prof. Sam Twiselton.

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About the Education Endowment Foundation

The Education Endowment Foundation (EEF) is an independent charity supporting teachers and school leaders to use evidence of what works—and what doesn't—to improve educational outcomes, especially for disadvantaged children and young people.



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One of the most important questions educational research can ask is how children learn. If we know how they process and retain information, we can adapt our approach to teaching accordingly and in turn, increase effectiveness.

At the Education Endowment Foundation (EEF), our mission is to ensure that pupils, regardless of their background, are able to reach the full extent of their potential. Developing our understanding of memory and how to balance cognitive load, and then applying this understanding in the classroom, has the potential to improve outcomes for all children.

This is why the EEF has produced this evidence summary on the impact of cognitive science approaches when applied in the classroom. Our hope is that by providing a transparent summary of the evidence that shows both the strengths and weaknesses of the current research, we can support schools as they consider how principles might make a difference to their pupils.

As with much evidence, the key message here is the importance of nuance. Principles from cognitive science are neither myths to be discounted, nor silver bullets that directly translate into accelerated progress.

There are still many questions to be answered on how principles from cognitive science can be applied in order to make the biggest positive difference for all young people. We need to know more about the effectiveness of approaches when used in different subjects, phases and their impact on disadvantaged pupils.

The future research work of the EEF can help fill some of these gaps. We will continue to work to generate and accurately summarise evidence on the approaches that can make a difference for all pupils, particularly the most disadvantaged.



Professor Becky Francis
Chief Executive

The role of cognitive science in the classroom

Cognitive science is being used increasingly to inform interventions, practice, and policy in education. Of particular interest to education has been research into motivation and reward, working memory and long-term memory, and cognitive load.

Findings from two areas of cognitive science have been especially influential: cognitive psychology, which is underpinned by interpretive, behavioural, and observational methods, and cognitive neuroscience, which is underpinned by brain imaging technologies. Many theories of effective learning have been derived from these research areas, including:

- **spaced learning**—distributing learning and retrieval opportunities over a longer period of time rather than concentrating them in ‘massed’ practice;
- **interleaving**—switching between different types of problem or different ideas within the same lesson or study session;
- **retrieval practice**—using a variety of strategies to recall information from memory, for example flash cards, practice tests or quizzing, or mind-mapping;
- **strategies** to manage cognitive load—focusing students on key information without overloading them, for example, by breaking down or ‘chunking’ subject content or using worked examples, exemplars, or ‘scaffolds’; and
- **dual coding**—using both verbal and non-verbal information (such as words and pictures) to teach concepts; dual coding forms one part of a wider theory known as the cognitive theory of multimedia learning (CTML).

These theories are already having an impact on teaching policy and practice in England. For example, the evidence review underpinning the Ofsted inspection framework draws significantly on approaches inspired by cognitive science:

‘It is, for example, becoming increasingly clear that using spaced or distributed practice, where knowledge is rehearsed for short periods over a longer period of time, is more effective than so-called massed practice.’

Our survey of teachers found that over 85% of respondents said that cognitive science strategies were central to their own approach to teaching. In addition, all early career teachers will be taught about memory and cognitive load as part of the Early Career Framework.

The approach taken in this evidence review

Many recent reviews have examined and explained the principles of cognitive science and how these principles *might* be applied in the classroom. Much of this evidence comes from studies in the psychology laboratory or from researcher-led trials. This evidence summary looks at the impact of these principles when they *have* been applied in the classroom. All of the studies included and summarised have taken place within schools.

In other words, this summary is focused on *applied* cognitive science. Applied research reveals many problems not encountered in laboratory or tightly controlled conditions. Classrooms are ‘messy’ and complex, with teachers needing to balance a wide range of considerations, both practical and pedagogical. Findings from the lab do not always translate into effective teaching and learning in the classroom and they may not apply across different pupil age groups, subject areas, and school contexts. With any educational approach, implementation in the classroom and variation in how the theories are translated can have a massive influence over whether the expected impacts are achieved.

By examining studies taking place in the classroom it is possible to build a picture of whether cognitive science principles work in practice, how they might be applied most effectively, and begin to understand the barriers and misapplications that mean that they sometimes have a weaker than desirable, or even negative, impact.

This report summarises the key findings and implications from a substantial evidence review; the full report can be found [here](#). The review comprises a theoretical review of cognitive science, a practice review on how approaches have been applied and received in English classrooms, and a systematic review of studies that have rigorously tested the impact of approaches.

Key Terms

‘Basic’ cognitive science—seeks fundamental understanding of learning, memory, and the brain. It typically uses experiments in controlled conditions to establish knowledge that is likely to have wide applicability.

‘Applied’ cognitive science—seeks to apply knowledge from basic cognitive science to solve practical problems. Here we are focused on cognitive science that is applied in the classroom that aims to improve learning of children and young people aged 3–18.

Main findings

Cognitive science principles of learning can have a real impact on rates of learning in the classroom. There is value in teachers having working knowledge of cognitive science principles.

Theories from **basic** cognitive science imply principles for effective teaching and learning. Principles include ‘spacing’ learning out over time, providing worked examples or ‘scaffolds’ to support problem-solving, and presenting information both verbally and visually. The applied evidence summarised does provide support for many of the principles of learning implied by basic cognitive science, albeit in specific contexts. For most of the strategies included in this review, cognitive science principles were significant factors affecting rates of learning and retention of information in the classroom. Most of the results could be explained using theories from basic cognitive science and practice-facing versions of these.

The evidence for the application of cognitive science principles in everyday classroom conditions (applied cognitive science) is limited, with uncertainties and gaps about the applicability of specific principles across subjects and age ranges.

Applied cognitive science is, so far, more limited and provides a less positive, and more complex, picture than the basic science. For many of the strategies that have been tested in practice, the evidence was restricted to particular age groups, subject areas, or learning outcomes. Applications of cognitive science outside

of these, while plausible given the basic science, are yet to be tested and found effective in the classroom.

Even approaches with indicative evidence of promise like **retrieval practice**, **spaced practice**, and the **use of worked examples** are, as yet, only supported by a few studies that examine their impact in everyday classroom conditions—delivered by teachers over long periods of time.

- With some approaches—like **interleaving**—there are studies with promising results but they have almost exclusively been tested in one subject area (mathematics). More generally, there are serious gaps and limitations in the age ranges, subjects, and learning outcomes studied for most of the strategies we reviewed. These gaps make the extent to which strategies apply across all age ranges and subject areas unclear.
- Some approaches—like combining verbal explanations with graphical representations, also known as **‘dual coding’**—are possible to implement poorly. While some studies show positive impacts on pupil outcomes, there are also multiple studies showing null or negative findings.

It is important to note that a lack of evidence is not the same as evidence that an approach is not successful. We should be cautious about concluding that because a principle is found to be ineffective in the lab or in one classroom context that it cannot be deployed effectively elsewhere.

Applying the principles of cognitive science is harder than knowing the principles and one does not necessarily follow from the other. Principles do not determine specific teaching and learning strategies or approaches to implementation. Considering how cognitive science principles are implemented in the classroom is critical.

Some accounts of cognitive science principles prescribe practice based on the strength of the underlying theory and claim that the behavioural or neuroscientific evidence justifies application across subjects and ages (see previous). These are inevitably interpretations of how principles apply in the classroom. The fact that many strategies have not been consistently tested in everyday classroom settings means that it is particularly important to think carefully about if, and in what circumstances, they are applicable and how we could implement them in a way that has a positive impact on pupil outcomes:

- Teachers looking to apply cognitive science principles in the classroom will need to consider how, and in what conditions, approaches informed by cognitive science might improve learning. The effectiveness of strategies is likely to depend on factors including the age of learners, learner prior knowledge, the nature of the subject and learning outcomes, and whether the approach is practically feasible—and make sure that they are successfully enacted.
- Special care should be taken to make sure that principles are successfully implemented, avoiding ‘lethal mutations’ when a practice becomes disconnected from the theory. For example, teachers have reported that dual coding sometimes means that irrelevant illustrations are added to presentations, which may be a distraction rather than a way of developing schemas and optimising cognitive load.

Schools should consider how—and in which contexts—to give teachers high quality CPD around cognitive science approaches, and enough time to test and incorporate approaches appropriately into their practice and for their subject and learners. Many teachers report that their main form of engagement with cognitive science is independent study.

Principles of cognitive science interact and should not be considered in isolation from each other, or without taking into account wider practical and pedagogical considerations.

There are clear links between the different approaches summarised within this review. In particular there are relationships between:

- approaches that consider how to optimise retrieval of information from the long-term memory: spaced learning, interleaving, and retrieval practice;
- approaches that consider the balance between didactic instruction and the pupil’s role in learning: strategies for working with schemas, learner-led strategies within managing cognitive load, cognitive theory of multimedia learning, and embodied learning.

Little research has effectively explored how distinct and similar strategies interact but it is clear that careful consideration is required to optimise mergers between approaches, for example, combining retrieval approaches with appropriate spacing.

The survey of teachers, review of the underpinning science, and the applied evidence in areas such as embodied learning suggest that social, emotional and physical aspects to cognition are also important for teachers to consider.

What is cognitive science?

Cognitive science is gaining increasing influence in education and many existing and developing educational approaches are described as ‘inspired by cognitive science’. Many of these approaches have been long practiced or described as effective pedagogy, without any reference to cognitive science—for example, quizzing pupils on topics has been common even without this being thought of as a form of ‘retrieval practice’.

The principles of cognitive science are typically derived from two areas of research:

- **cognitive psychology**—which is underpinned by interpretive, behavioural, and observational methods and in cognitive science has commonly derived principles from ‘lab studies’ in which different ways of influencing learning are tested and their results observed for individuals or small groups; and
- **cognitive neuroscience**—which is underpinned by brain imaging technologies such as functional imaging (fMRI) and tests principles by examining the physiological response of the brain rather than the behavioural response of participants in experiments.

One of the appealing prospects for both these approaches is that they might reveal something fundamental about learning, memory, and the brain. These understandings might be applicable across many contexts—to the extent to which humans share the same basic processes of learning and memory.

Important concepts and theories from cognitive science

Perhaps the most important concept used from cognitive science concerns the processes by which all of us commit information to our memories.

Memory can be separated out into **sensory**, **working**, and **long-term memory**. The process of going from seeing or hearing something to storing it in your long-term memory goes through several stages:

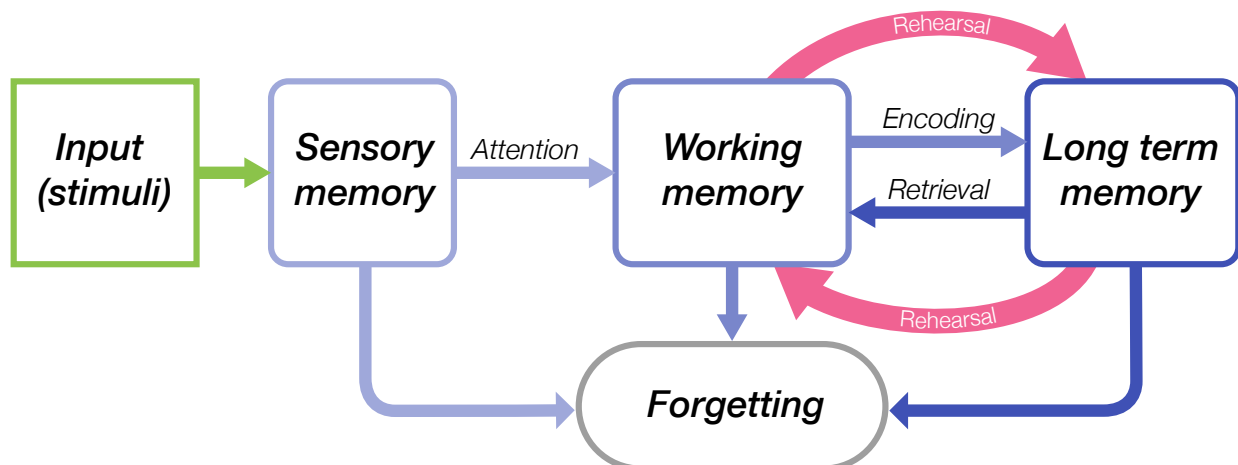
- an input (for example, hearing a teacher explain multiplication tables), the vast majority of which is forgotten (for example, the background noise, the clothes that the teacher is wearing, what is on the wall behind the teacher);
- a fraction of the input enters the **working memory** (for example, $2 \times 2 = 4$); and
- through attention and rehearsal, the information moves from the **working memory** to the **long-term memory**.

Many of the strategies derived from cognitive science focus on the crucial interactions between working memory and long-term memory and the important observation from cognitive science that our working memories have limited capacity.

Some strategies (reviewed in our section on **managing cognitive load** and also informing other areas such as **dual coding** and **embodied learning**) focus on the best ways of ensuring that the use of the working memory is optimised to focus on relevant learning content rather than distractions. Other strategies are more focused on practicing the process of retrieving information from the long-term memory (such as **spaced learning**, **retrieval practice**, and **interleaving**).

Key principles to remember

1. Learning requires information to be committed to long-term memory.
2. Information is processed through the working memory.
3. The working memory has limited capacity and can be overloaded.



Theory and practice divide

While discovering fundamental principles of memory or learning might be appealing precisely because they might be applicable to all pupils, the process of understanding whether a principle that works in the lab is also effective in the classroom—and the job of actually applying these principles—is far from straightforward. Understanding cognitive science and using lessons from cognitive science to improve teaching and learning are not the same thing. Applying a theory in the classroom requires understanding

whether something found in artificial conditions applies in specific, realistic conditions. It also requires overcoming many barriers that can prevent positive results even if the theory itself is sound.

Rather than reviewing the theories that underpin cognitive science, this review examines instances where these theories have been applied in real classrooms and how they have impacted the results of pupils.

Lost in translation: how to lose the power of a good theory

1. Misunderstanding an important part of the theory

Mr Bell has heard a lot about dual coding—and that learning can be enhanced by pictorial representations alongside information. He fills all of his classroom slides with quirky illustrations that he hopes will make the learning memorable. Unfortunately, the images end up distracting his pupils and increasing their cognitive load meaning that they struggle to remember the content itself.

2. Failing to equip teachers to deliver the theory

The Ofsted inspection framework prompts senior leadership to book some staff training on cognitive science. While the twilight session covers some of the principles behind spaced learning, staff are given no guidance on how to apply the approach. Senior leadership are not keen on any changes to school timetabling or the curriculum. No follow-up training is provided.

3. Failing to target the theory effectively

Mrs Rushby has heard that worked examples with incorrect information in them has been shown to be an effective way of teaching information while managing cognitive load. When she uses the examples in her Year 7 maths class, most pupils struggle to identify any errors—many of them end up reinforcing rather than addressing misconceptions and only a few of the top attaining pupils in the class respond positively to the task.

4. Or... the theory doesn't actually work in schools?

It might be that none or all of these factors are in play and that the theory itself has only ever been shown to work in highly controlled laboratory settings or for particular age ranges or subject areas. In medicine, treatments are often shown to reduce in efficacy as they move from lab-testing, to larger trials, to the real world.

How close to classroom practice?

One of the challenges when using evidence is understanding how close the research is to everyday classroom practice. We have consciously excluded any 'lab studies' from this review. If an approach has been tested outside of a classroom setting, it has not been included. This still, however, leaves large scope for studies that take place in real classrooms but that are further away from the reality of everyday teaching. For example:

- studies where the activity takes place in the classroom but the actual activities are delivered by a researcher rather than a teacher;
- studies where a teacher delivers an activity but their teaching is scripted and/or the researcher is present and providing more assistance than would be possible in a usual classroom setting;
- approaches that focus on very particular or narrow learning objectives or are tested for a very short period of time;
- studies where the outcome measured is very close to the intervention—for example, testing knowledge of specific words taught by a vocabulary intervention;
- studies that only look at a very small group of pupils in one particular school that may not be representative of all pupils; or
- studies that include only a small number of teachers, or the teachers are cognitive science experts and enthusiasts.

It is important to note that any of these studies might contain useful information on whether a cognitive science approach might be successful; for example, knowing whether the vocabulary intervention *does* actually teach the words intended is useful. But these studies do not necessarily mean that the approach will translate to similar results in every classroom. For example, if the approach is delivered by a researcher this conveniently sidesteps any issues with how easy it might be to train teachers to deliver the approach across a school.

Most scientific studies are designed to isolate and test the effect of a single principle or strategy. This is also true of even most applied studies, where researchers are usually focused on how a specific change in the teaching and learning can affect the learner outcomes. Researchers tend to use experiments across many schools to 'control for' or 'average out' all the myriad factors that affect teaching and learning. Teachers, on the other hand, must necessarily consider a wide range of practical and pedagogical factors. These factors interact in complex ways and change moment-to-moment in complex classroom environments.

During the review, researchers examined the literature to identify possible factors that might influence whether cognitive science principles work and are successfully implemented in a particular teaching and learning context. The table below summarises a range of factors relating to teachers, learners, classrooms, and the curriculum that might influence the impact of cognitive science strategies.

Possible factors affecting the impact of cognitive science techniques

Teachers, teaching	Pupil individual factors (potentially different for each student)
<ul style="list-style-type: none"> • Extent of teacher professional development and learning for the cognitive science technique • Teacher general pedagogical and subject-specific knowledge and skills • Level of teacher experience • Teacher motivation and enthusiasm for the cognitive science technique • Extent to which technique replaces or improves teacher's existing practice • (Many of the pupil factors, right, also apply to teachers) 	<ul style="list-style-type: none"> • Prior level of knowledge, in general and for the topic being learnt (and extent to which the teacher takes this into account) • Working memory capacity • Nutrition and hydration • Alertness/activity level • Mood and emotional state • General and learning-specific motivation • Personality and temperament • Special educational needs, difficulties, or disabilities • Learning behaviours and strategies • Age and maturity
Classroom/social environment	Activity, topic, and subject
<ul style="list-style-type: none"> • Relations in the classroom (teacher-pupil, pupil-pupil) • Culture of participation • Emotional environment • Disruption, noise, or distraction • Decoration and information • Access to learning resources 	<ul style="list-style-type: none"> • Subject or curriculum area (e.g., general differences in the nature of subject content and pedagogy) • Nature of specific learning content (e.g., complexity/element interactivity, novelty, connection with other learning) • Nature of specific learning activity (e.g., student-led, length, structure, resources)

This is not an exhaustive list. It is also important to note that whether or not a specific strategy (for example, dual coding) works in practice may be influenced by any one of these factors, and more likely most of them. As we describe above, even applied studies rarely study much of this variation. The best applied studies provide an authentic test of a strategy in realistic conditions; they are designed to take these into account and make sense of why and in what circumstances something works as well as providing a strong test of whether or not it does. Unfortunately, at present, well-designed applied studies are rare.

This evidence summary aims to be transparent about these challenges. Each section describes the evidence behind an approach and makes clear where these limitations apply.

As with any evidence base, it is important to remember that lack of evidence or lack of quality evidence is not the same as evidence of no impact. It is also possible, despite the complexity of teaching and learning, to identify guiding principles and 'best bets' for action. The evidence around cognitive science is evolving quickly and areas that rely on lab-based studies or studies with researcher delivery today may be tested in realistic classroom environments tomorrow.

This evidence summary

This evidence summary is based on a longer review, which can be found [here](#). The review document contains full details on the methodology of the review, which combines a theoretical review with a practice review and a systematic review, from which most of the evidence summaries below are drawn.

This summary document is split into seven sections based on different aspects of cognitive science and ways they might be applied in the classroom.

1. **Spaced learning**
2. **Interleaving**
3. **Retrieval practice**
4. **Managing cognitive load**
5. **Working with schemas**
6. **Multimedia learning (including dual coding)**
7. **Embodied learning**

Where these sections contain multiple approaches—for example, spacing across lessons and within lessons—there are separate sections summarising the evidence for each approach in more detail.

The final sections of the evidence summary discuss **mixed approaches** that combine the strategies listed above, and a discussion on some **overarching findings** from the review with regards to the promise of approaches based on cognitive science in general.

Key things to consider

- There is evidence to suggest that spacing teaching and learning of material over time and between intervals of unrelated content has the potential to improve pupil learning.
- More studies have examined the impact of spacing content across days and lessons than within individual lessons. Regarding the former, the evidence suggests a small positive impact across pupil ages and subject areas.
- A very limited number of studies examined spacing within lessons. These suggest promise but there is too little evidence to have confidence in this result.
- Implementing a spaced approach across days or lessons may present significant challenges, requiring careful integration with existing curriculum planning. Spacing within the confines of the existing curriculum and timetable may therefore be a more feasible application for classroom teachers to implement themselves.

What is the theory?

Spaced practice (also referred to as spaced learning, distributed practice, distributed learning, and the spacing effect) applies the principle that material is more easily learnt when broken apart by intervals of time. Spaced practice is often contrasted with ‘massed’ or ‘clustered’ practice, whereby material is covered within a single lesson or a linear and sequential succession of learning.

While spaced practice is thought to make learning more challenging for pupils as it prohibits information being held in the working memory, it may be able to increase the likelihood of knowledge being embedded in pupils’ long-term memory. In having pupils revisit key concepts, ideas, or skills over longer periods of time in which content is almost forgotten, teachers may be able to improve learning retention.

How do teachers use spaced practice in the classroom?

When adopting a spaced practice approach, teachers will fill spaces of time with learning content or activities that do not relate to the concept, idea, or skill being spaced. Where material is learnt across more than one lesson in a subject, spacing can be a natural consequence of the timetable with lessons in different subjects occurring in between the spaced learning. Within-lesson spacing is built into lessons plans and activity sequencing.

This is similar to the practice of interleaving, which also involves the use of spacing in a sequence of learning. This said, where spaced practice uses intervals consisting of unrelated content to encourage pupils to temporarily forget information before recalling their long-term memory, interleaving is more likely to be used to systematically switch between concepts and learning that are interrelated, encouraging learners to make distinctions and connections between similar yet slightly different learning material.

Some teachers also report using spaced practice as a form of retrieval practice, testing pupils' knowledge of previously taught content. This approach to spacing may be used as a form of revision as teachers utilise strategies such as multiple choice questions, recall grids, quizzes, or homework tasks to help pupils identify gaps in understanding and recall information from long-term memory. Such practices may be embedded into teachers' lesson planning, meaning that a portion of every lesson or time of day is dedicated to revisiting content.

Teachers might apply spacing principles to many aspects of teaching and learning. For example, spacing could be applied to instruction, practise, or assessment.

This review identified two forms of spaced practice that have been evaluated through research:

1. spacing across days or lessons; and
2. spacing within lessons.

An example approach

After teaching her class a new word, Ms Begum always makes a note of when she will revisit the word in other lessons throughout the coming week. Whether asking pupils to recall the definition of the word or designing tasks in which they must apply it in a new context, Ms Begum always ensures the word is returned to as this can help to embed it in pupils' long-term memory.

Implementation

Planning and implementing spacing across days and lessons takes careful curriculum planning that may present challenges. A pressure to cover lots of learning material within limited timeframes can lead to teachers feeling that there is little opportunity to reintroduce previously taught content. Curricula are also often organised in blocks to accord with school timetables, school textbooks, and prescribed by school leadership teams: this means that applying a spaced approach across days or lessons can sometimes be an organisational challenge beyond the remit of individual classroom teachers.

The evidence also highlights the value of considering how spacing can be informed and enhanced by classroom feedback and assessment. Teachers can use assessment to decide how often learning material should be revisited and the best time to increase the challenge or move on.

What is it?

Spacing across days or lessons might see pupils revisit a specific concept, idea, or topic several times over the course of one week, or once or twice a week for many weeks. The alternative to spacing is usually referred to as 'blocked' or 'massed' practice, where content is studied in a single learning session. Spacing is frequently combined with retrieval practice, often known as spaced retrieval practice.

What does the evidence say?

There are a significant number of studies showing that spacing across days and lessons can have a small positive impact on learning outcomes.

There are, however, some important limitations to the evidence. Substantial variation is found between study results with a significant number showing either no impact or a negative effect. Also, while spaced practice principles were tested in real classrooms within these studies, the approaches were rarely delivered by classroom teachers. Those that were designed and had the lesson materials provided by researchers.

What is the evidence based on?

The review found 18 studies of spacing across days and lessons.

- The ages of children in the studies ranged from 6 to 17.
- Studies covered several different subject areas including reading and vocabulary, science, and maths.
- In only six of the studies pupils were taught by teachers rather than researchers or computer packages. For these six, the training, guidance, or materials were provided by researchers.

An example approach

In his Year 4 class Mr Coales regularly breaks up the teaching of key concepts in science with other activities that distract pupils from what they have been learning. For example, after teaching his class about the different components of flowering plants (roots, stem or trunk, leaves, and flowers), Mr Coales supports his class to revise their previous topic on forces for ten minutes. After this, the pupils revise and apply previous learning on plant parts by labelling a diagram.

What is it?

Spacing within lessons involves the same content being repeated many times within one individual lesson, broken up by short intervals of time (often ten minutes long) in which unrelated content is taught. Although it may be common for key concepts, ideas, or definitions to be reused or revisited within single lessons, spacing within lessons differs from ‘massed’ or ‘clustered’ practice through the teacher’s choice to fill spacing intervals with unrelated learning or activities.

What does the evidence say?

The two studies on the impact of within-lesson spaced practice suggest it may have a positive effect on learning when compared with massed practice.

There are, however, significant limitations to the evidence. The range in available studies is very small, both in scale of research and authorship. Results are also varied within available studies. This means that the positive finding is merely indicative of potential rather than evidence of effectiveness.

Implementation

Fewer teachers report using spacing within lessons, suggesting spacing is more regularly considered as a method of revisiting content throughout a longer timescale. However, given that some teachers seeking to apply spacing across days or lessons highlight the challenge of spacing content within rigidly planned and time pressured curricula, spacing within lessons may be a more feasible method of drawing on the benefits of spacing without making major adjustments to the organisation of the timetable or curriculum.

This said, given that spacing is thought to increase the difficulty of learning for pupils by challenging them to revisit almost-forgotten information, frequent use of spacing within lessons could detrimentally affect some pupils’ motivation.

What is the evidence based on?

The review found two studies of spacing within lessons.

- The ages of children ranged from 4 to 11 in one study and 13 to 15 in the second study.
- The study with 4- to 11-year-olds involved the teaching of history and geography, whereas the older study only looked at the teaching of biology.

Both studies were conducted in a single school in England meaning there is insufficient variation in the population to test for generalisable impact.

Key things to consider

- Evidence suggests interleaving may be an effective strategy for developing upper primary to early secondary (age 8–14) pupils' ability to select appropriate methods for solving mathematical problems.
- While plausible, there is little or no applied evidence of interleaving being applied to topics outside of mathematics or for younger or older pupils.
- The rationale for interleaving is that it may support learners to discriminate between two similar concepts or methods. Teachers may be able to increase the level of challenge presented through interleaved tasks by introducing more similar items of learning.

What is the theory?

Interleaving involves sequencing tasks so that learning material is interspersed with slightly (but not completely) different content or activities, as opposed to undertaking tasks through a blocked and consecutive approach. While similar to spaced practice, interleaving involves sequencing tasks or learning content that share some likeness whereas a spaced practice approach uses intervals that are filled with unrelated activities.

By repeatedly reintroducing pupils to similar but slightly different content or activities, interleaving is thought to assist the drawing of comparisons between related but discrete items of learning. When completing a series of related activities, pupils may refine their ability to select the more appropriate method for answering certain types of questions.

Interleaving therefore draws on the use of spaced intervals thought to assist long-term memory retention, as seen in **spaced practice**, as well as the benefits of making comparisons to develop more complex schemas, as highlighted in **working with schemas**.

How do teachers use interleaving in the classroom?

The evidence we reviewed on interleaving in the classroom has, with the exception of only one study, examined its use in Key Stage 2 or Key Stage 3 mathematics to develop pupils' ability to select appropriate strategies to solve problems.

In the wider literature and teacher accounts, many believe that the benefits of interleaving extend beyond strategy choice in maths. Some other topics of application include students learning different artists' styles, grammar in the language curriculum, physics equation practice, preparation for MFL oral exams (where 'students have to be ready to talk at length about a large number of topics'), maths teaching, and primary languages.

An example approach

When teaching fractions to his class, Mr Hodiak likes to test his pupils as this can help to identify areas for improvement and gaps in understanding. To ensure that his pupils have to think hard about how to solve fractions, Mr Hodiak interleaves problems with different numerators and denominators. Mr Hodiak thinks that by requiring his pupils to identify the subtle differences between these varied types of problems, he can embed learning and improve pupils' ability to select appropriate strategies when solving fractions in the future.

What has been researched?

The research focused mostly on interleaving mathematical problems that pupils independently solve through selecting appropriate solutions. Problems could be presented to pupils through computer software, workbooks, or via a teacher provided with a script, or researchers.

What does the evidence say?

When compared to a blocked or sequential approach, there is moderate positive evidence that interleaving can better support Key Stage 2 and Key Stage 3 pupils to select appropriate solutions when solving mathematical problems.

There are, however, some important limitations to the evidence: 11 out of 12 studies were in maths, and within these many focused on interleaving tasks that required learners to select a solution strategy before implementing it.

While the approach may be transferable across tasks or subjects, we have no evidence to support this. The evidence is also based on a set of highly scripted, research-controlled studies that use mostly workbooks or computer software for delivery, so we cannot be sure how applicable these findings are to teacher-directed interleaving.

Implementation

There is some evidence to suggest that interleaving is well suited to problem-solving tasks where pupils select strategies to generate solutions.

It is possible that the more similar interleaved items are, the harder pupils must think to differentiate between them, increasing the level of challenge. As pupils become more able to discern the differences of tasks and select appropriate strategies, it may be appropriate to interleave more similar problems as this should require more nuanced discrimination.

Some teachers express concern over confusing students through interleaving, particularly those with lower attainment who may take comfort in compartmentalising their knowledge. It is possible that some pupils need to have strong foundational knowledge of learning content prior to making effective comparisons between interleaved tasks or concepts, particularly if this content was originally covered in a different unit of work.

What is the evidence based on?

The review found 12 studies of interleaving.

- The ages of children in the studied ranged from 8 to 14.
- Studies covered mostly maths topics such as fractions, algebra, subtraction, and geometry. One study was in physical education.
- In five of the 12 studies pupils were taught by teachers or with some (mostly scripted) teacher

Key things to consider

- Short, low-stakes tests or ‘quizzes’ in various formats can be a cheap, easy-to-implement way of recapping material that might strengthen pupils’ long-term ability to remember key concepts or information.
- Planning test difficulty is particularly important—pupils should be able to retrieve at least some of the content they are tested on.
- Quizzing or low-stakes testing may also reveal misconceptions. How will you ensure that where these emerge pupils are supported to overcome them?

What is the theory?

Retrieval practice describes the process of recalling information from memory with little or minimal prompting. Low stakes tests (such as individual questions or quizzes) are often used as methods of retrieval practice as these require pupils to think hard about what information they have retained and can recall. When used in this way, tests can be a strategy *for learning* in addition to being an assessment *of learning*. The retrieval practice evidence base (both basic and applied) suggests that testing learning is often a better strategy *for learning* than restudying or recapping the same information.

Cognitive science informs us that memory has a ‘strength’, referring both to how easily something can be recalled and how deeply information is embedded. When content is studied and recalled, both types of memory strength increase, meaning that information is more easily accessible and that this accessibility is more durable.

It is thought that by testing for knowledge of previously learnt content, retrieval practice encourages pupils to strengthen their memory on key concepts

or information. Also, the testing process makes pupils aware of weaknesses in their memory and gaps in their understanding, thereby supporting self-monitoring of learning that can lead to the development of strategies for improvement.

How do teachers use retrieval practice in the classroom?

The most common application of retrieval practice in the classroom is using low-stakes quizzes to encourage learners to retrieve information from their long-term memory. Retrieval practice is often contrasted with recapping material—where the teacher reminds pupils of previous learning rather than asking learners to recall it themselves.

The low-stakes quizzing can take many forms including:

- multiple choice questions;
- short-answer fact questions;
- short problem-solving;
- true/false questions;
- labelling diagrams;
- image recognition;
- recitation of quotes or definitions; and
- list creation.

Retrieval practice might be combined with other approaches—for example, providing targeted feedback on the outcomes of the low-stakes quizzes.

An example approach

At the beginning of German class, Mrs Key asks the class to think back to their learning from the previous week and to list as many of the German words for animals as they can on a sheet in front of them.

What has been researched?

The research summarised here examines any activity that requires students to recall information from memory rather than recapping, revising, or restudying the information. This can include partial recall of information supported by hints, cues, scaffolds, or other contextual information. A common way of achieving this in a classroom is through low-stakes quizzes, questions, and tests.

What does the evidence say?

When compared to no recap activity at all, the evidence for using quizzes is moderate and generally positive.

Most studies that compare quizzing to forms of re-study or recap have a positive impact—though there are high levels of variation in the evidence and some negative results.

One of the weaknesses of the evidence is that many of the approaches are designed and delivered by researchers rather than classroom teachers. There are examples of teacher-delivered quizzing having a positive impact but given the lack of studies, a firm conclusion is not possible. There are also questions about whether retrieval practice is as effective for more complex or subtle learning beyond rote factual recall.

Despite these limitations, the positive impact of the retrieval studies, the good theoretical grounding of the practice, and the low cost of implementing low-stakes testing and quizzing generally mean that it is a promising approach that teachers should consider.

Implementation

Teachers have identified numerous ways that retrieval practice can be implemented and very few barriers to implementation were identified. Practices identified by teachers included:

- use of knowledge organisers to rehearse learning points;
- retrieval grids;
- labelling diagrams with gradual reduction of information; and
- true or false, multiple choice, cloze procedure, and finish the sentence.

At present, the evidence is uncertain about which activity formats are most effective and whether retrieval practice can help students learn ‘higher-order’ or more subtle learning content beyond factual recall. There are, however, a number of factors that teachers should consider when implementing retrieval practice—particularly around whether additional support is required for pupils that struggle. When one provides a test to a group of students, they will—to varying proportions:

- successfully retrieve some answers;
- be unable to retrieve others; and
- erroneously retrieve some answers (for example, misconceptions).

A key consideration when implementing retrieval approaches should be how to determine optimal task difficulty. If pupils are unable to retrieve information successfully then this is unlikely to increase memory strength, however, the evidence is currently uncertain about optimal level of challenge. It should be noted that quizzing has other potential benefits beyond encouraging pupils to retrieve information. For example, testing might identify gaps in knowledge and where pupils erroneously retrieve wrong answers, feedback might be used to support learning and help pupils overcome misconceptions.

An interesting challenge is how to combine retrieval practice with spaced learning. Spacing lessons might make pupils less able to retrieve information. If teachers are implementing both approaches together, they could carefully monitor whether the approaches are additive and check that spacing does not reduce the ability of pupils to retrieve information successfully. Spaced retrieval can also potentially answer questions about which learning content to prioritise in a crowded curriculum. Moreover, revisiting previously-taught content as part of retrieval practice—while it is likely to be preferable to restudying or reteaching (assuming that the material was successfully learnt)—may also encroach on the time available to teach new material.

What is the evidence based on?

The review found 21 studies that compared retrieval practice to restudy.

- The studies spanned students from early years to older pupils aged 16–17. There was a good spread across primary and secondary pupils
- Studies looked at a wide range of subjects including language, history, maths, science, and English.
- Only one of the 21 studies was delivered by regular class teachers. Others were delivered by researchers (in keeping with the aim of this review, all studies did take place in school rather than lab settings).

Key things to consider

- The evidence around strategies that seek to manage cognitive load is promising and indicative of the value and importance of teachers seeking to manage cognitive load.
- While this typically involves reducing unnecessary information and providing additional structure and support, sometimes optimising cognitive load involves increasing the challenge and quantity of relevant information provided.
- Worked examples are appropriate for learning with a defined, step-by-step structure. Their typical application has been in secondary science and maths, where all of the applied evidence we reviewed is located.
- It is also possible to provide incomplete or partially incorrect worked examples to increase challenge and ‘fade’ out the support provided.
- Other strategies for managing cognitive load include scaffolding through, for example, providing appropriate guidance, prompts, instructions, templates, and tools.
- Collaborative group work can share—and thereby reduce—cognitive load, with peer support acting analogously to worked examples and scaffolds. The evidence suggests that optimising cognitive load in group-work settings is possible, albeit challenging.

What is the theory?

A key challenge for educators is that **working memory** is limited. There are lots of things that can cause it to be overwhelmed. An example is when problem-solving learners might be presented with a large amount of complex information and asked to follow a series of problem-solving steps. Where a student has limited prior knowledge committed to their long-term memory this might lead to their working memory being overwhelmed, impairing learning.

The aim of strategies that focus on managing cognitive load is not to minimise cognitive load but to *optimise* it—minimising unnecessary load and ensuring that working memory remains focused on the information that is being taught.

How do teachers manage cognitive load in the classroom?

Understanding cognitive load has implications for general teaching practice—for example, avoiding distractions or anxieties that might overload the working memory. Teachers report practices aimed at managing cognitive load, for example, chunking content into manageable pieces of learning, creating frameworks and scaffolds to support understanding of key concepts, thinking about economy of language when giving verbal instructions, and decluttering presentation materials.

This review has identified three specific practices that teachers might use to manage cognitive load:

1. using worked examples to support learners to apply and develop knowledge;
2. providing ‘scaffolding’ and other forms of support such as prompts, cues, or targeted instructions to help learners navigate the working memory demands of tasks; and
3. using collaboration between pupils so that they can share the demands of problem-solving tasks.

An example approach

When teaching her class about titration calculations, Dr Turner demonstrates how to organise the information in a question within a grid format.

This breaks down the steps involved in the overall calculation, helping to ensure pupils complete each step in the correct order. Dr Turner always models how to use the grid correctly when teaching it to pupils.

	KOH	H ₂ SO ₄	
Concentration mol/dm ³	0.102	0.047	$n = \frac{cV}{1000}$
Volume cm ³	23.1	25.0	
Moles	2.36×10^{-3}	1.18×10^{-3}	
mole ratio	2	→ 1	
$c(\text{H}_2\text{SO}_4)$			
$\frac{1.18 \times 10^{-3}}{25} \times 1000 = 0.047 \text{ mol/dm}^3$			

Image © Kristy Turner reproduced with permission

What is it?

Worked examples provide students with step-by-step, or part-by-part, demonstration of a task that makes clear the required product (that is, answers or output) and the process of completing the task. They often include diagrams that illustrate each step. They relate to cognitive load theory because it is thought that they can support pupils in applying understanding and applying knowledge without overloading working memory by requiring pupils to solve problems while they are first beginning to understand an approach. Approaches will often ‘fade’ information—gradually reducing the level of explanation provided by the examples. In some circumstances, pupils are given incorrect worked examples and asked to identify errors in the process.

What does the evidence say?

There are a large number of studies showing that using worked examples can have a positive impact on learning outcomes.

There are, however, some important limitations to the evidence. No studies were found that tested using worked examples outside of maths and science. While the principles may be transferable, we have no evidence of the application outside of these subjects. The evidence is also very focused on older pupils.

What if the evidence was there?

The review found 22 studies on worked examples. Seven of these studies focused on the use of incorrect or incomplete worked examples.

- Most studies took place with secondary age students.
- All studies focused on maths and science.
- In only eight of the studies were the worked examples delivered by regular class teachers rather than computers or researchers.

Implementation

One of the biggest challenges identified around the use of worked examples was the ‘expert reversal’ effect. The structure and support provided by worked examples that appear to benefit learners in an unfamiliar and complex topic can become redundant or even harmful as pupils become more familiar with the problem. It is important to pay close attention to pupil prior understanding and the progress being made. The evidence also shows that individual working memory capacity varies, and can be greatly affected by emotions such as anxiety.

There is some evidence that using incorrect examples and asking pupils to identify errors in a worked example can have a positive impact as learning progresses. However, a key factor identified is matching levels of prior learning to the strategy. Strategies where pupils are asked to identify problems with incorrect worked examples need to be carefully tailored to the prior knowledge of the pupils. Several studies showed that these approaches had positive effects for advanced pupils but mixed evidence for pupils with low prior attainment.

One of the biggest challenges identified around the use of worked examples was making sure that the exemplification itself is of high quality and does not introduce any new misconceptions, unless it is specifically designed to test their identification.

Another challenge identified around managing cognitive load was that many existing materials from core textbooks contain designs that are likely to split attention and overload the working memory. There is a balance to be struck between breaking down information into manageable steps or ‘chunks’ and keeping related material in one place to avoid split attention. Where pre-prepared materials are poor, it can be challenging for teachers to have capacity to design worked examples that do not introduce misconceptions, that are well-tailored to the content, and do not contain extraneous design elements that overload the working memory (see **cognitive theory of multimedia learning**).

An example approach

Whilst reading aloud to class, Mrs Walker chunks the sections of reading into manageable lengths and stops to explain difficult concepts to the class. The students were supported, through the use of a structured worksheet, to identify key terms, organise ideas from the text in sequence, and to identify themes and the main ideas in the text.

What is it?

There are many common learning objectives and curriculum areas that can potentially overwhelm working memory, especially when learning a new topic. Not all lend themselves to step-by-step and defined solutions that can be supported through worked examples. There are many techniques teachers use to support students; many of these are designed to focus learners on key information, guide them through a process, or support them to record or organise information for reference.

These approaches typically use some kind of guidance to support pupils while engaging in tasks, the aim being that the instructions reduce cognitive load and help learners navigate the working memory demands of the task. It might involve, for example, including prompts, cues, instructions, definitions, templates, and tools as resources to support a task. Scaffolding is a general teaching strategy and concept. The evidence here focuses on a subset of this, specifically designed to optimise cognitive load.

What does the evidence say?

This approach covers a wide number of different practices. For example, some studies examined intelligent tutoring systems that automated support as learners went through tasks while another provided explanatory notes during reading comprehension activities.

Despite the variety in approaches, there is consistent evidence that well targeted scaffolds, guidance, and schema-based support are an effective approach to support students to solve problems or learn from complex tasks in Key Stage 2 to Key Stage 4.

What is the evidence based on?

The review found 16 studies of using scaffolds, guidance, and schema-based instruction.

- The ages of children in the studied ranged from 8 to 16.
- Studies covered a number of different subject areas including maths, reading, history, and science.
- In seven of the studies pupils were taught by their regular teacher.

Implementation

Not all prompts or cues during learning tasks will reduce the burden on working memory. For example, the study identified with a negative impact included cues that were motivational rather than instructional. Cues should be targeted in such a way that they provide instructional support involving key elements of the problems that are being solved, for example, explanations of difficult vocabulary.

Accounts of managing cognitive load from the theoretical evidence base indicate that reducing the level of support (or ‘fading’) is beneficial to learners. Pupils that already have strong foundational knowledge are less likely, for example, to benefit from the provision of key term definitions and

providing support is likely to increase cognitive load. While the classroom evidence is too limited to confirm this account, the studies identified in the review did find that level of expertise determined the effectiveness of scaffolding approaches.

Some studies indicated that when fading was used to gradually reduce scaffolding, it was more effective when adapted to the changing knowledge of pupils rather than fading at a fixed rate. One of the risks teachers identified around scaffolding was pupils becoming reliant on the scaffolds. Carefully monitoring pupil expertise and gradually reducing scaffolding might reduce the risk of reliance on scaffolds developing.

An example approach

(Adapted from Zambrano et al., 2019)

When learning quadratic equations, pupils are given partial information, which means they must work together to solve the problem. Equation values are unpacked to distribute them among the pupils (for example, for $-15x^2$, each member would receive $-5x^2$). Rather than holding all pieces of information in their head, group members depend on others' information to solve the problem.

What is it?

Collaborative problem-solving activities are those in which learners work together to complete a problem or complex task. Collaborative problem-solving is a general teaching strategy and concept. The evidence here focuses on a subset of this, specifically designed to optimise cognitive load.

What does the evidence say?

There is some evidence to corroborate the theory that collaborative learning can help manage cognitive load.

The evidence, however, is not entirely positive and seems to indicate that collaborative work is not suited to every type of problem-solving activity.

The evidence is also very strongly focused on learning in mathematics. No studies examined collaborative problem-solving in the humanities or social sciences.

What is the evidence based on?

The review found nine studies that focused on the optimisation of cognitive load through collaboration when problem-solving.

- Eight of the studies focused on learners aged 12 to 16. The other study took place with children aged eight and nine.
- Six of the studies focused on mathematics, with two in biology and one in ICT.
- Most of the interventions were overseen by the regular class teacher.

Implementation

The evidence suggests that collaborative learning is likely to reduce cognitive load as learners work together and share information. What is less clear is how this can be designed to optimise cognitive load for individuals within the group, ensuring that all are attending to relevant and challenging information relative to their prior level of understanding.

If communication within a collaborative working strategy is ineffective, cognitive load may be increased by the effort of organising others and reduced in ways that are unhelpful as only some members of the group engage with key information. Providing support on effective collaborative working communication strategies, giving clear instructions on tasks, and allowing ways of working to develop in consistent groups of pupils may all reduce the cognitive load of collaborative activities.

Teachers using collaborative problem-solving approaches outside of mathematics should be aware that there is limited evidence of its effectiveness in other disciplines and should carefully monitor whether the activities are reducing cognitive load and having a positive impact on learning.

Key things to consider

- Teachers should consider pupils' prior knowledge and how this might influence their organisation of new knowledge and experience of misconceptions.
- There is some evidence that concept mapping and comparison can improve pupil learning, although the variation in impacts suggests challenges with implementation. Indicative evidence suggests that it is how students engage with information—and the extent to which they self-generate and organise information—rather than any particular format, mapping, or organising information that matters.
- When using concept mapping and comparison, it is important teachers know why they are employing these strategies and have a plan for assessing pupils' understanding to ensure key conclusions have been taken from tasks.

What is the theory?

Schemas (sometimes referred to as mental models, scripts, or frames) are structures that organise knowledge in the mind. When learning, the mind connects new information with pre-existing knowledge, skills, and concepts thereby developing existing schemas. Teachers often want to develop and refine learners' prior conceptions as opposed to teaching something entirely new. Approaches that

compare, organise, and map concepts try to make schemas clear and visible and are thought to support learners to organise and extend their ideas.

Working with schemas can prove challenging for teachers as schemas are formed in the minds of pupils as they relate new content to prior knowledge: schemas are therefore shaped by every individual's preconceptions, prior experience, and personal development of understanding.

Also, schemas are never fixed in their contents or arrangements meaning that teachers are unlikely to know exactly how their pupils' minds organise new content. However, the flexible nature of schemas does mean that specific teaching and learning strategies may be able to foster a more desirable order to a learner's pre-existing and developing knowledge.

There are several approaches to working with schemas, many of which focus on pupils organising, comparing, and elaborating on their ideas to develop more complex mental structures. Some approaches include:

- problem-based learning whereby pupils learn through their struggle to apply existing knowledge to a challenging task;
- using comparisons and analogies to add depth or address misconceptions; and
- elaborating or questioning concepts and ideas to strengthen, develop, and transfer learning.

How do teachers work with schemas in the classroom?

Many teaching and learning approaches that are informed by cognitive science are in some way influenced by schema development. For example, by presenting information in thematic groupings to manage pupils' cognitive load, teachers may also assist efficient schematic organisation.

The review identified three specific approaches to working with schemas. These are:

1. concept/knowledge mapping and organisation;
2. schema/concept comparison and cognitive conflict; and
3. elaboration and self-explanation.

There was, however, insufficient evidence to review the possible impact of elaboration and self-explanation.

An example approach

After studying a text with her class, Ms Howarth uses her knowledge of the text and experience teaching the same text with other classes to create knowledge organisers that collate the most crucial foundational concepts and knowledge onto a single A4 page. These resources help pupils make links between ideas and concepts, often grouping information by big overarching themes from the text, key quotes with annotations on language devices, and relevant information on the social and historical context in which the text was written. Ms Howarth often provides pupils with the organisers ahead of end-of-unit assessments to help them self-assess existing knowledge and inform the writing of practise essays.

What is it?

Organising key concepts or knowledge on maps or organisers. It is thought this approach may help pupils receive, organise, and extend schematic knowledge of a topic in a more efficient way, encouraging connections between related items of learning.

What does the evidence say?

There is some evidence to suggest that concept/knowledge mapping can have a positive impact on pupil learning.

The evidence, however, is not entirely positive and seems to indicate that if tasks are pitched beyond pupils' level of prior knowledge mapping approaches can have negative impacts.

The evidence is also varied in the types of approaches concept/knowledge mapping is used for, suggesting it is not clear which tasks are best suited to this form of organisation. Many tasks took the form of teachers or learners creating a mind map to summarise and organise the key ideas in a text.

What is the evidence based on?

The review found 15 studies on concept/knowledge mapping and organisation that refer to contemporary cognitive science.

- The ages of the students in the studies ranged from 8 to 17. Most studies focused on the 8 to 14 range.
- Studies looked at a range of subjects including science, maths, geography, and text comprehension in either literacy or general studies.
- Only six of the 15 studies were mostly delivered by regular teachers. Others were designed and delivered by researchers, involved independent study via computer software, or were delivered by teachers but heavily scripted with instructional materials.

Implementation

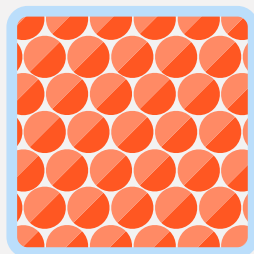
There is some evidence to suggest that concept mapping and organisation may be more effective when maps are generated by teachers rather than pupils, or when pupils already have good prior knowledge in an area. It is thought that when generating maps themselves, pupils may experience cognitive overload as they try to concurrently organise and engage with material. Indicative evidence suggests that it is how students engage with information—and the extent to which they self-generate and organise information—rather than any particular format, mapping, or organisation of information that matters.

Teachers should consider why they are using mapping tasks and ensure pupils' attention is focused on the most useful components of the activity. Teachers may choose from a range of strategies for pupils to engage with content, including: summarising, (re)organising it themselves, drawing, imagining, self-testing, self-explaining, filling in gaps, elaborating, enacting in some way, or teaching other pupils.

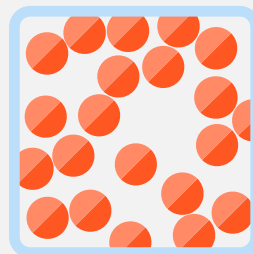
An example approach: Teaching about the particle model of gases

Adapted from Burrows et al., (2017 p. 47)

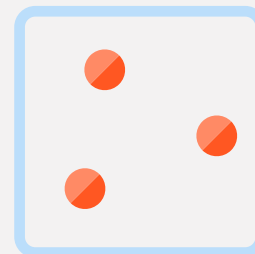
One of the key things that pupils need to know about gases is that there is empty space (a vacuum) between the particles.



Solid



Liquid



Gas

These ideas can, however, conflict with pupils' preconceptions. Even if pupils know that the particles in a gas have gaps between them, they often think that the space between them is full of other things such as bacteria, pollutants, or oxygen.

What is it?

Studies in this area examined activities that compared contrasting, complementary, or conflicting concepts or examples as means of supporting pupils to differentiate between items of learning.

What does the evidence say?

Overall, the evidence on the possible impacts of approaches in this area are mixed, with some negative and neutral results amidst a majority of studies showing positive impacts on pupil learning.

The variation in the findings suggests pupils may find it difficult to learn from comparisons or conflicts. Care should be taken to ensure pupils process differences in depth and derive the correct conclusions (rather than misconceptions) from the materials presented.

What is the evidence based on?

The review found ten studies on schema or concept comparison.

- The ages of the students in the studies ranged from 10 to 18. Most students were of secondary age, the majority between 11 and 14 years old.
- Studies looked at a narrow range of subjects, including only maths or science.
- Only three of the ten studies were delivered by teachers who received training to implement interventions. The other studies predominantly used workbooks or computer programmes for delivery.

Implementation

The wider evidence in this area and practice-facing interpretation and guidance suggests that care is needed in selecting comparisons to support learning. How to ensure comparisons and analogies clarify rather than confuse concepts appears to be a key consideration. Pupils may benefit from the support of a scaffold to help them explain the differences between concepts, supporting them to make detailed comparisons with correct conclusions. For example, a teacher might provide reflection questions to help pupils specify the cognitive and metacognitive processes they have used when comparing concepts. Regarding the former, the teacher might ask, 'What features of the diagrams did you compare to highlight the differences between them?' Or with regard to metacognitive processes: 'What did you find difficult about comparing the two diagrams and how did you overcome that difficulty to highlight the differences between them?'

It is also important to use assessment to gather information on what pupils have concluded by making comparisons as this may uncover misconceptions that need addressing before moving on or revisiting during a later lesson.

Key things to consider

- The evidence around the use of multimedia is mixed: while many studies are positive, others show low or null effects.
- Promising approaches use multimedia to support the learning of complex information, often with older pupils.
- Multimedia approaches can be challenging to implement successfully. How are we to ensure that the multimedia does not increase cognitive load?

What is the theory?

Dual coding theory is based on the theory that working memory has two distinct components, one that deals with visual and spatial information and another that deals with auditory information. By presenting content in multiple formats, it is possible that teachers can appeal to both subsystems of the working memory, which subsequently strengthens learning.

It is thought that given the specialised nature of the two subsystems of working memory, a larger amount of content can be understood with more richness when conveyed through multiple formats without overloading working memory.

While this information is useful to teachers as it suggests learning may be more effective when information is presented in this way, the many different formats in which information can be presented—such as text, images, diagrams, equations, or combinations of any of these—means that teachers must make difficult decisions about which format to use without necessarily knowing how this will affect pupils' cognitive load and learning.

Given the large variety of practice reviewed in this area, we decided to frame the area using a slightly broader theory: the cognitive theory of multimedia learning (CTML). This theory builds on ideas of dual coding, cognitive load, and generative learning (where students actively integrate new ideas with existing ideas). CTML describes organising, selecting, and integrating multimedia information into coherent representations and combining them with prior knowledge¹. It has three core assumptions:

- there are two separate channels for information (that is, dual coding theory);
- each channel has a finite capacity; and
- learning is an active process of working with this information.

How do teachers manage cognitive theory of multimedia learning in the classroom?

While approaches that explicitly describe themselves as 'dual coding' have become very popular recently, teachers have always illustrated concepts or ideas through images or illustrations. We examine the evidence for three distinct uses of multimedia:

- visual representations or illustrations;
- diagrams; and
- spatial, visualisation, and simulation approaches.

¹ Mayer, R. E. (2005). Cognitive theory of multimedia learning. *The Cambridge handbook of multimedia learning*, 41, 31-48

An example approach

(Adapted from Moreno et al., 2011)

When learning about circuits in science, pupils are provided with images at different levels of abstraction. Sometimes these include pictures of actual lights, while at other times they use the formal symbols for them.

There are also significant limitations to the evidence base. While all of the studies took place in school rather than lab conditions, few of them accurately reflect usual school provision. Most were delivered by researchers, used researcher tests, and were often delivered in one short session that was scripted for consistency. While these studies might give useful insight into the principles of how visual representations might have an impact in the classroom, they tell us less about whether impacts will be transferable to regular teacher practice.

What is it?

Using visual representations and illustrations involves learners being presented with, or creating, an additional image, picture, or icon that symbolises, illustrates, or represents aspects of the content being learnt. Studies in this group involved the presentation of additional visual information to a task or concept that could potentially be learnt without the visual. In some cases, the visual representation was provided, in other cases produced by the learner.

What does the evidence say?

While many of the impacts of the studies identified are positive, results were mixed. Studies frequently reported no effect or harmful effects. The strategies included in this group were varied. It is likely that a regrouping that organised the studies by theoretically important aspects (such as whether the images were created by, or provided to, students, or the information content of the images) might have revealed a clearer picture about the conditions in which visual representations can support learning.

What is the evidence based on?

The review found 34 studies relating to visual representation and illustration.

- There were no studies of Key Stage 1 or early years, but a good representation of pupils aged 7 to 18.
- Most of the studies took place in science and maths, although other subjects were represented, including geography, history, and vocabulary learning.
- Most studies were not delivered in typical school conditions: they were often small interventions, delivered by researchers rather than teachers, and often delivered in one short session.

Implementation

The limitations in the evidence mean that teachers should think carefully about *how* they use visual representations to support learning. While the evidence is too weak to tell us what works, there are some lessons from the theoretical evidence, which might support stronger effects in the classroom.

Ensuring that images are informational rather than decorative means that they are more likely to support learning rather than placing an unnecessary strain on cognitive load.

Teachers highlighted that while it may be straightforward to include illustrations while teaching, implementing approaches in a successful way so that they are more than ‘drawing pictures for the sake of it’ is more challenging. Surveyed teachers voiced concerns around whether dual coding in particular had become misunderstood and reduced to ‘pretty icons’ and complex graphic organisers.

An example approach

(Adapted from Coleman, McTigue and Dantzler, 2018)

When learning about the water cycle, pupils are presented with diagrams with labels and process information that illustrate the different steps of the cycle. Evaporation is shown through an illustration of water rising from the sea to clouds, while a ray from the sun shines onto the sea. An arrow illustrates the direction of travel and a note explains that the evaporation is caused by heat from the sun's energy and occurs in water in lakes, rivers, oceans, and on land.

What is it?

Using diagrams is a subset of the evidence base on visual representations that represents or organises learning content or process information schematically. In most cases, the diagrammatic representation was an object of learning in its own right. The diagram goes beyond illustration and decoration to represent relevant concepts or phenomena and, additionally, how they are organised or structured.

In the evidence, diagrams are often contrasted to textual representations of information and sometimes combined with other practices— for example, spaced restudy.

In some studies, children are shown diagrams to explain concepts while in others children are encouraged to draw diagrams to summarise learning.

What does the evidence say?

As with the wider evidence on visual aids, the evidence on diagrams shows that while most studies have positive effects, many have null or negative effects.

Similar to the evidence on visual aids, a key limitation is that studies often were not delivered by teachers in usual classroom conditions. Most of the studies were delivered by workbooks or computer programmes.

Implementation

Diagrams are a subset of other visual representations and illustrations and many of the same lessons apply. One of the distinct factors in a diagram, as opposed to an illustration, is considering how concepts are structured or organised. It is important that the visualisation does this accurately. It is possible, for example, for inaccurate diagrams to reinforce misconceptions.

What is the evidence based on?

The review found 14 studies related to the use of diagrams in the classroom.

- Twelve of the studies involved pupils between 12 and 16. None of the studies focused on early years.
- Studies were concentrated in maths and the sciences, with one study of technical illustrations in geography.
- Most of the studies were delivered by workbooks or computers.

An example approach

(Adapted from Barner et al., 2016, 2018)

When doing calculation tasks in maths, pupils are taught to use the mental image of an abacus to visualise the way the calculation takes place. As they complete sums, they imagine their mental abacus and use it to support their calculations.

Implementation

The limitations in the evidence base for spatial, visualisation, and simulation approaches mean that there are limited insights on how teachers might apply these approaches successfully in the classroom. There is significant variation in how these approaches have been applied. Teachers should carefully consider how the visualisation strategy is being used, for example, is it inherent to the subject, or is it a method of retrieval or scaffolding?

What is it?

Spatial, visualisation, and simulation approaches support children to imagine learning content, or representations of it, often in order to simulate, manipulate, or organise concepts and schemas across time or space. In some cases, visualisation is inherent to the learning objective (as, for example, in geometry); in others, it is used as a form of retrieval and rehearsal (for example, imagining a story); in other cases it is used as a scaffold for problem-solving (that is, visualising as a way of analysing or anchoring a learning object in memory).

What does the evidence say?

While the studies identified have small to moderate positive effects, the limitations of the evidence base make it difficult to assess the effectiveness of the strategies.

The number of studies is small and there is real variation between the approaches that go beyond practical differences in delivery.

The focus on mathematics across all but one study means that there is limited information on the promise of the approach for other subjects.

What is the evidence based on?

There were only seven studies that focused on spatial, visualisation, and simulation approaches.

- All of the studies focused on primary aged pupils.
- All but one of the studies focused on mathematics. The final study focused on reading comprehension.
- Two of the studies were delivered by regular teachers.

7. EMBODIED LEARNING AND PHYSICAL FACTORS

Key things to consider

- There are lots of reasons other than academic outcomes to consider physical factors at school such as nutrition, physical activity, and sleep hygiene.
- The evidence around embodied learning is currently limited and the studies in this area of the review were loosely grouped. Nonetheless, the evidence we reviewed suggested considerable promise for approaches involving the body and physical activity to support learning.
- The studies we reviewed explored a range of embodied and physical strategies including the use of gesture, actions, playground physics and maths, and tracing (for example, using the index finger to trace over a geometry worked example or water cycle diagram).

What is the theory?

Embodied learning and physical factors refer to strategies that engage and make use of movement and the body to support effective learning. More generally, embodied learning often also encompasses the role of emotions in learning—but this is something we have not included in the scope of this review. Most studies reviewed in this area emanated from searches for visual representation and the coding of information.

In contrast to many of the other strategies explored in this report that primarily focus on improving the mind's ability to acquire, organise, and apply new knowledge and skills, approaches that use the body and physical movement to support teaching and learning work under the assumption that the mind is closely related to the body and its sensory experience.

It is thought that by designing tasks and activities that appeal to pupils in a multisensory way, teachers may be able to make new information more easily comprehensible and memorable. Some actions and approaches for using embodied learning and physical activity in the classroom include play, enacting, gesturing, movement, and tracing.

Another area of cognitive science includes evidence around exercise, nutrition, and sleep. While these factors have important links to cognitive science, we have not summarised the evidence in detail as they were outside the scope of the review.

How do teachers use embodied learning and physical factors in the classroom?

Schools frequently support physical factors that might interact with learning. Some examples include:

- physical exercise as part of regular school timetabling;
- incorporating physical activity into non-PE lessons;
- breakfast clubs to increase nutrition; and
- sleep hygiene education.

Embodied learning approaches have most often been used in primary schools and use movement around the classroom while teaching other subjects, for example, throwing beanbags to each other during counting tasks. Other examples are tracing, the use of gestures when teaching, and play-based learning approaches.

An example approach

(Adapted from Cook, Duffy and Fenn, 2013)

When teaching equations, the teacher uses hand gestures when referring to different sides of the equation. When saying the word ‘one side’, the teacher sweeps her hand back forth beneath the left half of the equation. When the teacher says ‘the other side’, she sweeps her right hand back and forth below the right half of the equation.

What has been researched?

The research summarises approaches that enact or represent concepts through movement of the whole body or part of the body (such as gestures or tracing) including learning or enhancing learning through the use of the body’s sensory or motor capabilities. Included studies relate to physically doing, experiencing, or acting out or playing with the learning object, including both concrete and representational approaches, and in particular gestures and actions.

What does the evidence say?

The evidence in this area is consistently positive. Studies comparing embodied cognition approaches were found to have larger impacts on learning than normal curriculum delivery.

There are, however, a number of limitations to the evidence base. A key challenge in interpreting this evidence is that there may be missing studies as no direct search of ‘embodied learning’ or similar terms took place.

Almost all of the studies took place in primary schools, so caution should be applied when trying the approaches with older pupils.

Similar to other approaches, there is limited evidence from studies that are comparable to usual in-school practice. Studies have typically involved delivery from researchers and have often only looked at short-term outcomes for pupils.

Implementation

Some of the wider evidence discusses the links between the gestures of teachers with cognition—particularly when teaching younger pupils.

While the evidence in this area is too limited to pull out any direct implications for practice, the theoretical evidence does point to links between things like gestures and other cognitive science approaches like dual coding and managing cognitive load. Like with dual coding, teachers might consider how to ensure that gestures provide additional support rather than creating distractions that put a strain on cognitive load.

What is the evidence based on?

Unlike other strategies, the studies on embodied cognition and physical approaches were found through general searches of cognitive science rather than specific searches of the approaches. This means that this evidence may not be a comprehensive summary of the approach. Fourteen studies were found in total.

- The studies mostly focused on primary school children with ages ranging from 5 to 14.
- There were studies of maths, science, and language (including reading comprehension and vocabulary).
- Ten of the studies were designed and delivered by researchers. Other studies were either delivered by teachers in collaboration with researchers or by using digital technology.

An example approach

When co-designing a new Year 8 curriculum, the head of English and Key Stage 3 lead think hard about the sequencing of schemes of work and how key concepts and items of learning can be revisited over several weeks (spaced learning) and can be built upon to support pupils in developing complex mental models with a secure grasp of foundational knowledge (as seen in *Working with Schemas*). For example, when considering how best to develop pupils' ability to organise the structure of literary texts, they introduce some learning around Freytag's pyramid during the study of *Macbeth* at the start of the year before building on this through a later scheme of work on the sequencing of sections in short story narratives.

To ensure that teachers are aware of the rationale for these curriculum design choices, the head of English and KS3 lead provide time to develop and explain the curriculum during a departmental meeting. Furthermore, to support teachers responsible for delivering the new curriculum, the English department also make time to discuss the possible misconceptions pupils might experience while learning about narrative structures and develop worked examples and scaffolds that will assist learners with differing needs.

Key things to consider

- Mixed strategy programmes were amongst the strongest examples of applied research, often testing the strategies in realistic conditions and at scale. Such programmes are of interest to teacher educators and school leaders as potential vehicles for aligning teaching and learning with multiple principles from cognitive science across many teachers and schools.
- The evidence on mixed strategy programmes was hard to interpret as it was difficult to ascertain which specific strategies were influencing pupil outcomes.
- The seven programmes reviewed provided a mixture of positive and null outcomes. Many of the applied, mixed strategy programmes also suffered with implementation challenges.
- It was unclear whether these challenges related to the organisational aspects of the programmes, school improvement efforts more generally, or from the nature of the cognitive science strategies in question.

What is the theory?

While not exclusively, these programmes often embed strategies throughout curricula or learning topics, meaning they are most frequently implemented at a school or departmental level. Some mixed strategy programmes also include professional development as school leaders seek to develop teachers' fluency in knowledge and use of cognitive science principles.

It is thought that by increasing knowledge and use of cognitive science strategies, teachers can harness the evidence base of how people think and learn to support pupils more effectively.

How do teachers implement mixed strategy programmes in the classroom?

Most of the mixed strategy approaches are programmes that are implemented at the level of the school, either through professional development or curriculum development.

What has been researched?

Approaches in which two or more cognitive science informed strategies are used together to test the combined effect.

What does the evidence say?

Some studies show mixed strategy programmes can have a positive impact on pupil outcomes, although several null or mixed results suggest challenges with implementation.

Mixed strategy programmes are likely to link to school improvement processes and may also involve curriculum design and professional development. The effectiveness of these other school practices could therefore influence the success of any large-scale approach within this area.

Implementation

When implementing one or a combination of cognitive science informed strategies, it is important teachers consider the applicability of research evidence to their context and intended use of approaches. The findings of studies that involve predominantly independent study by pupils or technology-based interventions give some insight into the impact of approaches, but this evidence often focuses solely on the strategies being tested and does not explain how best to integrate cognitive science principles into conventional classroom practice. Considering how to implement cognitive science strategies in a way that complements existing school and classroom practices is of high importance.

Teachers' understanding of cognitive science principles may be a crucial component of effective implementation of mixed strategy programmes and therefore professional development is likely to be key. Careful monitoring of teacher beliefs about cognitive science prior to implementing a programme may be a useful way of judging the readiness of the school or department for the intended change. Following this, consistent modelling of the new strategies, observing ongoing delivery, and providing ongoing feedback and support can help staff make lasting change to their practice.

What is the evidence based on?

The review found eight studies reporting tests of mixed strategy programmes.

- The ages of the students in the studies ranged from 11 to 14.
- Studies looked at a narrow range of subjects, including only maths or science.
- Five of the eight studies were delivered by regular class teachers who received professional development in addition to curriculum resources to implement strategies.

Cognitive science principles of learning can have a significant impact on rates of learning in the classroom. There is value in teachers having working knowledge of cognitive science principles.

Theories from basic cognitive science imply principles for effective teaching and learning. Principles include ‘spacing’ learning out over time, providing worked examples or ‘scaffolds’ to support problem-solving, and presenting information both verbally and visually. The applied evidence summarised does provide support for many of the principles of learning implied by basic cognitive science, albeit in specific contexts. For most of the strategies included in this review, cognitive science principles were significant factors affecting rates of learning and retention of information in the classroom. Most of the results could be explained using theories from basic cognitive science and practice-facing versions of these.

The evidence for the application of cognitive science principles in everyday classroom conditions (applied cognitive science) is much more limited, with uncertainties about the applicability of specific principles across subjects and age ranges.

Applied cognitive science is far more limited and provides a less positive, and more complex, picture than the basic science. For many of the strategies, the evidence was restricted to particular age groups, subject areas, or learning outcomes. Applications of cognitive science outside of these, while plausible given the basic science, are yet to be tested and found effective in the classroom.

- Even approaches with indicative evidence of promise like **retrieval practice**, **spaced practice**, and **the use of worked examples** are, as yet,

only supported by a few studies that examine their impact in everyday classroom conditions—delivered by teachers over long periods of time.

- With some approaches—like **interleaving**—there are studies with promising results but they have almost exclusively been tested in one subject area (mathematics). More generally, there are serious gaps and limitations in the age ranges, subjects, and learning outcomes studied for most of the strategies we reviewed. These gaps make the extent to which strategies apply across all age ranges and subject areas unclear.
- Some approaches—like combining verbal explanations with graphical representations, also known as **‘dual coding’**—are possible to implement poorly. While some studies show positive impacts on pupil outcomes, there are also multiple studies showing null or negative findings.

It is important to note that a lack of evidence is not the same as evidence that an approach is not successful. We should be cautious about concluding that because a principle is found to be ineffective in the lab or in one classroom context that it cannot be deployed effectively elsewhere.

Applying the principles of cognitive science is harder than knowing the principles and one does not necessarily follow from the other. Principles do not determine specific teaching and learning strategies or approaches to implementation. Considering how cognitive science principles are implemented in the classroom is critical.

Some accounts of cognitive science principles prescribe practice based on the strength of the underlying theory and claim that the behavioural or neuroscientific evidence justifies application

across subjects and ages (see previous). These are inevitably interpretations of how principles apply in the classroom. The fact that many strategies have not been consistently tested in everyday classroom settings means that it is particularly important to think carefully about if, and in what circumstances, they are applicable and how we could implement them in a way that has a positive impact on pupil outcomes:

- Teachers looking to apply cognitive science principles in the classroom will need to consider how, and in what conditions, approaches informed by cognitive science might improve learning. The effectiveness of strategies is likely to depend on factors including the age of learners, learner prior knowledge, the nature of the subject and learning outcomes, and whether the approach is practically feasible—and make sure that they are successfully enacted.
- Special care should be taken to make sure that principles are successfully implemented, avoiding ‘lethal mutations’ when a practice becomes disconnected from the theory. For example, teachers have reported that **dual coding** sometimes means that irrelevant illustrations are added to presentations, which may be a distraction rather than a way of developing schemas and optimising cognitive load.

Schools should consider how—and in which contexts—to give teachers high quality CPD around cognitive science approaches, and enough time to test and incorporate approaches appropriately into their practice and for their subject and learners. Many teachers report that their main form of engagement with cognitive science is independent study.

Principles of cognitive science interact and should not be considered in isolation from each other, or without taking into account wider practical and pedagogical considerations.

There are clear links between the different approaches summarised within this review. In particular there are relationships between:

- approaches that consider how to optimise retrieval of information from the long-term memory: spaced learning, interleaving, and retrieval practice;
- approaches that consider how to present information effectively and support students to work through information without overloading working memory: dual coding and multimedia theory of learning, strategies to optimise cognitive load such as scaffolding and use of worked examples, and embodied learning approaches; and
- approaches that consider the balance between didactic instruction and the pupil’s role in learning: strategies for working with schemas, learner-led strategies within managing cognitive load, cognitive theory of multimedia learning, and embodied learning.

Little research has effectively explored how distinct and similar strategies interact but it is clear that careful consideration is required to optimise mergers between approaches, for example, combining retrieval approaches with appropriate spacing.

Future work

Many of the classroom approaches inspired by cognitive science are promising and knowledge of cognitive science is an important part of understanding how pupils learn. There is, however, much more work to be done to understand in which contexts findings from the basic science are applicable and effective in everyday classroom conditions, and how these can be implemented. The EEF will continue to evaluate approaches that provide scalable programmes or training for the effective deployment of cognitive science principles. We will also continue to fund teacher choices trials, which seek to rigorously assess the non-programmatic teacher techniques for deploying cognitive science in the classroom.

The current evidence base on cognitive science applied to the classroom is largely focused on how individual learners process and remember information. Social, emotional and physical aspects to cognition and learning receive less attention in the applied evidence found in this review. The survey of teachers, review of the underpinning science, and the applied evidence in areas such as embodied learning however suggest that social, emotional and physical aspects to cognition are also important considerations for research and practice.

Basic science. The study of phenomena and scientific laws, often referred to as ‘fundamental’ or ‘pure’ science.

Applied science. Using approaches informed by conclusions from basic scientific knowledge in practical, real world contexts.

Working memory. Where information that is being actively processed is held—it is where ‘thinking’ happens.

Long-term memory. A ‘store of knowledge’ that is constantly updating and evolving.

Cognitive load. The amount of information our working memory can hold at any one time.

Schema. A pattern of thought that organises categories of information, and the links between them. Schemas are stored in long-term memory.

Spaced practice. Distributing learning and retrieval opportunities over a longer period of time rather than concentrating them in ‘massed’ practice.

Interleaving. Sequencing learning tasks so that similar items are interspersed with slightly (but not completely) different types of items rather than being presented consecutively.

Retrieval practice. Using a variety of strategies to recall information from memory, for example flash cards, practice tests or quizzing, or mind-mapping.

Dual coding. Using both verbal and non-verbal information (such as words and pictures) to teach concepts.


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Education Endowment Foundation
5th Floor, Millbank Tower
21–24 Millbank
London
SW1P 4QP

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