WORKING MEMORY:
RESEARCH INTO PRACTICE

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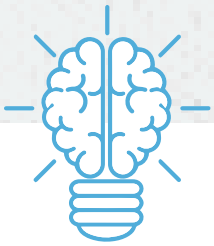
FOREWORD

This guidance grew out of a collaboration between an academic and a teacher, with the desire to co-produce materials that reflected the expertise provided by those two fields, bringing together best-evidence from research and from classroom practice. Our aim is to provide a resource for teachers to help support children in the classroom, in particular children who may have difficulties with working memory. It is designed for anyone working with early years, primary, or secondary school children. We use 'teacher' here to include anyone involved in the teaching, or in supporting the teaching, of children.

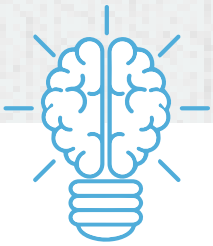
Co-production has been at the heart of this project, and we are grateful to those who have provided feedback and advice in bringing this guidance together, including academics, teachers, and educational psychologists. We would like to thank Dr Richard Allen (University of Leeds), Dr Nazam Hussain and Dr Joe Wilson (Education Psychology Team, Bradford), Laura Reynolds (Crossflatts Primary School), Sarah Campbell (Beckfoot Upper Heaton School), Dr Amy Atkinson (University of Lancaster), and Professor Joni Holmes (University of East Anglia) for their invaluable comments that helped us to improve the guidance. We would also like to acknowledge the Bradford Opportunity Area, who have helped support this project. In particular, we would like to acknowledge the seminal work by Professor Susan Gathercole, whose research forms the basis for so much work in this area, including her book 'Working Memory and Learning: A Practical Guide for Teachers' (Sage, 2008).

We have deliberately tried to keep this guidance short, whilst also communicating all the key information. Sections include a summary of the research and an explanation of working memory, key behavioural signs associated with working memory difficulties, and practical suggestions to support children in the classroom.

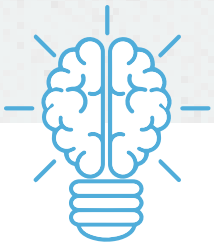
This project has been possible because of the Centre for Applied Education Research, which promotes multi-disciplinary partnerships between academics, practitioners, and policy-makers. A pdf version of this booklet is available as a free download on the CAER website. In addition, the CAER website provides links to an A3 poster that summarises the guidance, as well as materials that we have developed to help identify children with working memory difficulties, including a behaviour check-list screening questionnaire (caer.org.uk/working-memory-in-the-classroom/).



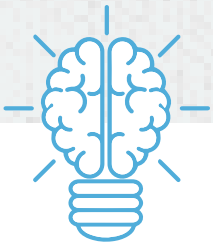
Information in working memory will be lost after about 30 seconds if it is not actively rehearsed or refreshed.



We can only hold up to about 4 chunks of information in working memory at any one time.

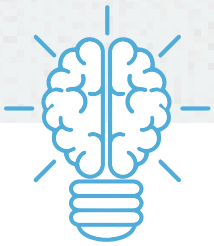


Working memory has a strong association with educational attainment, such as Key Stage Tests, in both primary and secondary school.

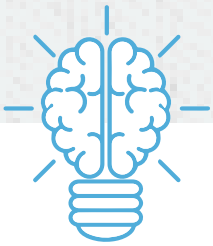


Our national survey of over 1400 educational professionals found that more than 75% over-estimated the duration of working memory, believing that information can be held there for several minutes, or several hours, without actively rehearsing or refreshing it.

DID YOU KNOW?



Our national survey of over 1400 educational professionals found that the majority provided a reasonable estimate of the capacity of working memory. But over 25% were incorrect, with most over-estimating the amount of information that could be held.



Our national survey of over 1400 educational professionals found that most were aware of, and had used, strategies to support children with working memory difficulties in the classroom. However, 20% were unable to list any strategies to support children and 40% had not actually used any such strategies.

ABOUT THE AUTHORS

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CAER was created via the Opportunity Area initiative, funded by the Department for Education. CAER is a partnership between the Universities of Leeds & Bradford, the Department of Education, Bradford Institute for Health Research, and Bradford Research School.

WORKING MEMORY: RESEARCH SUMMARY

Working memory refers to the ability to hold in mind and manipulate a limited amount of information over short periods of time (Baddeley, 2012; Cowan; 2017). We use working memory all the time in our day-to-day lives: stopping and asking for directions whilst out driving and having to maintain those instructions in mind; trying to keep a running total of how much we are spending in a shop when we cannot use an external aid such as the calculator on our mobile phone; meeting a new person at a party and being able to remember their name long enough to then introduce them to others; remembering the quantities of different ingredients we are mixing together based on a recipe when we are no longer looking at the page.

These tasks are not always easy. We may find that we can hold on to the first two parts of the directions, but struggle to maintain the rest. Or, after a few minutes of chatting, we may realise we have forgotten the name of the person we just met. These illustrate two key ways in which our working memory is limited: capacity and time. We can only hold and process a limited amount of information in working memory, and we can only hold on to that information for a short period of time before needing to engage in strategies to maintain the information. These strategies can include verbal rehearsal of the information, either out loud or in our head, or use of mental imagery. Or we can make use of external aids, such as a notepad or a calculator, to store information in a way that reduces the need to keep it in our working memory. The use of external aids is sometimes referred to as 'cognitive off-loading'. That is, we offload aspects of the task on to the environment so that we reduce the demands being made on our working memory, releasing capacity to help with successful task completion (Berry, Allen, Mon-Williams, & Waterman, 2019).

When considering how long we can maintain information in working memory, this is shorter than many people realise. If we cannot engage in rehearsal, or other

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ways to refresh the information in working memory, then it is likely to be lost after about 30 seconds. In an online survey we ran with over 1400 teaching professionals, we found that only about one fifth of respondents could estimate an appropriate time limit for working memory, with the majority over-estimating how long we can retain information in working memory. Most respondents reported that it lasted over several minutes, and many reported that information could be held for hours (Atkinson, Allen, & Waterman, 2021).

With regards to capacity, researchers now agree a typical adult can hold up to around four 'chunks' of information in working memory (Cowan, 2001). Teachers are sometimes familiar with Miller's (1956) "7 +/- 2", which is often illustrated by the digit recall task where a list of digits are read out, one at a time, and the task is to repeat them back, straight away, in the same order. Many adults can correctly recall up to about 8 or 9 digits. But researchers now think that this longer sequence is supported by people starting to rehearse the digits, or by visualising the numbers to support the verbal input. When we run very controlled experiments to stop people from being able to rehearse, or to recruit other cognitive resources to support the task, we find the limit to be between 3 and 5 items or 'chunks'. Indeed, chunking is a way of increasing the amount of information we can hold in working memory. If we are trying to recall a string of letters (where we are prevented from rehearsing or other similar processes) then we might only

remember 5 from the following string – UKSLTIBMJFK. However, if we are familiar with certain acronyms, we could remember the whole sequence as four chunks: UK – SLT – IBM – JFK. This also illustrates how long-term memory is linked to working memory. We can utilise our knowledge in long-term memory (where, for example, we know and recognise that SLT is the common abbreviation for Senior Leadership Team) to enable us to link the new information into those pre-existing structures.

In addition to the limits of capacity and time, information can also be lost, or stored inaccurately, due to distraction or interference. For example, as we are maintaining the rolling total of the cost of items in our shopping bag, there is loud music playing in the shop which makes it hard to focus our attention on the task at hand. Or as we try to recall the correct page in the recipe book, we find that information from a similar recipe, that we had also recently looked at, interferes with our ability to remember the relevant quantities.

Working memory is even more limited in children, and researchers have shown that working memory capacity develops across childhood, reaching adult-like levels by about 15 years (Gathercole, Pickering, Ambridge, & Wearing, 2004a). Alongside this are large individual differences in working memory ability. In a class of seven-year-olds you could have a child with the working memory ability of a typical four-year-old, and some with the working memory ability

of a typical ten-year-old. These individual differences, and in particular the reduced working memory abilities of some children, are significant within the education context. Working memory underpins learning, and is strongly associated with academic success. Several studies have shown that working memory ability is linked with attainment on standard tests of educational attainment, including Key Stage tests (Gathercole, Pickering, Knight, & Stegmann, 2004b; Holmes & Adams, 2006).

When we consider that we need working memory to hold on to and manipulate information, it is easy to see how this is essential for learning. Children have to use working memory to complete almost any task within the classroom. For example, carrying out a maths problem with multiple steps, where they have to hold on to an intermediate step in the problem-solving sequence, whilst then manipulating other information to complete the task. When writing, a child has to retain ideas for subsequent sentences whilst writing the current one, as well as remembering grammatical or syntactical rules which also influence how and what they write. When checking work, they have to hold in mind what they want the text to say whilst reading the text they have produced. Further, all this has to be performed whilst maintaining a focus on the particular over-arching goal or objectives of the task, for example, linking two different poems, or writing about what they did at the weekend. Reading also places heavy demands on working memory. When learning to read, children have to remember the shapes of different letters, link that to the sound associated with that letter, and then learn how to combine letters to create words. For older children, reading texts also taxes working memory, particularly texts that are challenging or introduce novel information. Comprehension of a particular text requires storing recently read words for long enough to then link with the following words in that sentence or section. These then need to be held for a sufficient period of time to create a meaningful interpretation.

Children have to use working memory to complete almost any task within the classroom

Working memory is also essential when following instructions, and children with reduced working memory ability have particular difficulties with following instructions, even relatively simple ones such as, 'Put away your reading books, take out your spelling book, write the date at the top of a new page, and then turn to face the front' (Waterman et al, 2017). A child with

working memory difficulties might put their reading book away, but then forget what they were supposed to do next. This often leads to these children appearing forgetful, or as if they have not paid attention, when in fact they have simply forgotten what they were meant to do.

Given how important working memory is for learning, and for success in the classroom, it is essential that we create a teaching environment that supports children's working memory, and, in particular, supports children with reduced working memory abilities. One solution that has been proposed is working memory training, where children complete regular tasks that are designed to place increasing demands on working memory, with the idea that this will improve their working memory ability. Unfortunately, whilst some companies present evidence suggesting this training is helpful, the best analysis looking at a wide range of studies on this topic has shown that its usefulness is very limited. Children often get better at the specific task(s) they complete in the training, but this almost never translates across to improvements in learning, or to classroom activities that call upon working memory, in any consistent or sustained way (Melby-Lervåg & Hulme, 2013; Sala & Gobet, 2017).

It is essential that we create a teaching environment that supports children's working memory.

Therefore, the best way to support working memory in the classroom is to structure the environment and to adapt teaching practices. We need to be mindful of tasks that create heavy demands on working memory, try to reduce those demands where possible, and provide appropriate support structures and strategies for children with reduced working memory ability to enable them to compensate for working memory difficulties.

Models of working memory

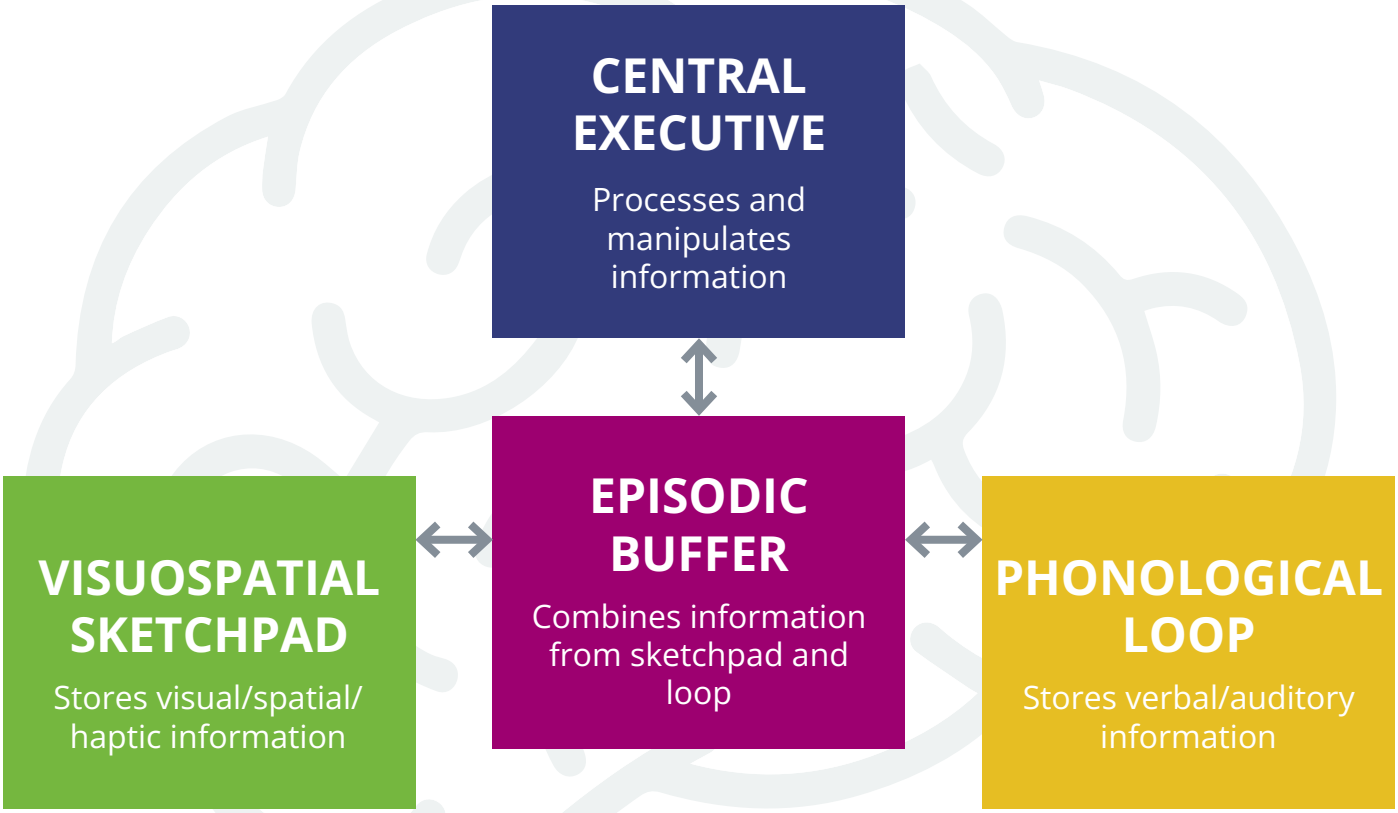
One of the most widely cited models of working memory is the multi-component model by Alan Baddeley and colleagues (Baddeley & Hitch, 1974; Baddeley et al., 2021). They propose that working memory contains several separable components. This includes specialised storage components for verbal or auditory information (the phonological loop), and for visual, spatial, and haptic information (the visuospatial sketchpad), along with a store capable of combining different types of information together in conscious awareness (the episodic buffer). The final component is referred to as the central executive; this acts as a supervisory

Cognitive Load Theory

Cognitive Load Theory (CLT) (Sweller, 1988) is instructional theory based on what we know about working memory. The core aspects of CLT stress the importance of optimising the demands made on working memory to maximise learning, and of explicit instruction accompanied by plenty of opportunity for practise and feedback. These key ideas are complementary to the guidance outlined in this booklet. However, some of the detailed proposals made by CLT researchers are less well supported by the research. CLT proposes that there are three types of cognitive load: intrinsic (related to the material being presented), extraneous (related to the delivery or teaching of the material), and germane (which seeks to encourage 'deep' learning or processing). Intrinsic and extraneous cognitive load, and how to reduce it, map well on to the key areas that we outline in this guidance. However, germane cognitive load has been less well defined by the CLT research field, and when considering how to apply ideas on germane load to the classroom, it can sometimes appear to conflict with those based on issues relating to extraneous cognitive load. This guide does not explicitly address CLT but presents recommendations based on the best available evidence within the field of working memory research. However, the recommendations in this guide will also serve to reduce cognitive load.

attentional system, controlling the flow of information to and from the storage components, and is responsible for the processing and manipulation of information (see diagram).

There are other theories of working memory, and they do differ from one another in the finer details of how they propose that working memory functions. However, they all agree that working memory is limited, both in the amount of information that can be held and the length of time over which it can be maintained, and that working memory is more limited in early childhood and develops well into the teenage years (Cowan, 2017). Further, proponents of the multicomponent model acknowledge that the separation of functions within working memory into verbal and visuospatial, and storage and processing, is not completely clear-cut, and that there is some overlap between these different aspects of working memory. However, separating them in the model provides a useful framework within which to understand working memory, and is supported by a wide range of evidence. In addition, the most widely used tests of working memory tend to include separate tasks that reflect the different components of this model (with the exception of the episodic buffer). Some tests tap into the ability to store verbal information (such as the forward digit recall test), some tap into the ability to store visuospatial information (such as the Corsi block test), and finally there are others that tap into the ability to both store *and* process information (such as the running span test or the backward digit recall test).



The Multicomponent Working Memory Model (Baddeley & Hitch)

Working Memory and Long-Term Memory

Working memory has a very short duration. Unless information is actively maintained in working memory, for example by rehearsing or refreshing, it is likely to be lost within 30 seconds. As we rehearse or refresh that information, we are engaging in processes that can help transfer information to long-term memory. In theory, we can hold information in long-term memory indefinitely. However, information in long-term memory can decay over time, or suffer from interference. Interference is when similar memories can become confused, for example, you are trying to remember what you had for lunch last Sunday, but you have memories of many different Sunday lunches from the last few weeks and months, and these interfere with your ability to single out the specific instance you want to remember. So, long-term memory is not perfect but it does allow us potentially to store information over very long periods of time.

With regards to capacity, long-term memory is also potentially limitless, unlike the very limited capacity of working memory. However, in most circumstances, information from long-term memory that is required to complete the task at hand still has to be brought into working memory. Exceptions to this mainly involve routine motor activities that have become automatic (e.g., tying your shoelaces), and priming. Nonetheless, for most classroom activities, you cannot simply bypass the limited capacity of working memory by tapping straight into long-term memory.

However, information that is securely stored in long-term memory is more familiar, which in turn helps with accessing and processing that information in working memory. Also, we create schemas, or webs of knowledge, within long-term memory for related information. This means that we can then 'chunk' that information, by combining several separate pieces of related information into one 'chunk', which in turn frees up some of the capacity of working memory. Bringing one chunk of related information into working memory from long-term memory reduces demands compared to remembering lots of separate items of new information. For example, a schema or network of information in long-term memory on WWII will place a lighter load on working memory resources than when we first encounter this information and each fact is effectively a single, isolated 'item'. This is why tasks that require lots of new pieces of information, are not familiar, or do not tap into any schemas in long-term memory, are likely to place higher demands on our working memory.

RECOGNISE AND IDENTIFY WORKING MEMORY PROBLEMS

There are several behaviours that tend to be associated with reduced working memory ability. Some of these behaviours can also be the product of other difficulties or learning disorders. However, when taken in the round, the behaviours outlined below can help detect children who may be at risk of working memory deficits.

Attention

Children with working memory difficulties can often appear distracted, or lose concentration easily. Problems with attention are obviously associated with attention deficit disorder, but children with working memory difficulties also struggle with attention and may find it difficult to maintain focus on tasks. This can often lead to abandoning the task at hand, because they cannot remember what they are supposed to be doing next. They may also become distracted by other activities (because they cannot complete the given task), or they might appear to 'zone out'.

Children with working memory difficulties often struggle to follow instructions or to complete multi-step tasks. They might miss out steps within a multi-step process, or only complete the first part of the instructions.

Forgetting

Children with working memory difficulties tend to have problems with remembering. Common behaviours associated with this are: putting up their hand but then forgetting what they were going to say; being unable to remember what they were supposed to do next; being unable to remember what they were currently doing on a task; making place-keeping errors where they might skip parts of a task, or where they repeat part of a task (such as writing a word down twice successively); and struggling to hold information in mind. Where forgetting is partial, it is quite common for the children to remember the information at the beginning of the task, and then forget the rest.

Following Instructions

Children with working memory difficulties often struggle to follow instructions or to complete multi-step tasks. They might miss out steps within a multi-step process, or only complete the first part of the instructions.

Needing extra support

Children with working memory difficulties may ask to be reminded what they are supposed to do next more often than other children, or may need more active reminders from staff about the task at hand. They might also more often seek support or help from peers regarding activities or instructions.

Academic progress

Reduced working memory ability is consistently associated with lower educational attainment, and children with working memory difficulties often struggle with key classroom activities such as reading and writing, as well as more subject specific topics such as maths and science. They often struggle to learn new material, and tend to take longer to incorporate it into existing knowledge.

These behaviours also form the basis for the Working Memory Classroom Screener that has been developed in collaboration with Professor Susan Gathercole. This 20-question screener is free to download and use, and helps with identifying children at risk of working memory difficulties. We are also developing other materials to support teachers in identifying children with working memory difficulties. All these materials can be found on the CAER webpages (caer.org.uk/working-memory-in-the-classroom/), with full instructions on how to use them.

EVALUATE
WORKING MEMORY DEMANDS

Before we can address the working memory demands of learning activities, we first have to identify those working memory demands.

Unfamiliarity

Pupils will have varying degrees of pre-existing knowledge that they bring to the subject at hand. There will be links between different pieces of knowledge, some of which was learnt at school and some of which was learnt elsewhere. This web of knowledge in long-term memory for a particular topic or area can be referred to as a schema. Schemas will expand and change when new knowledge is learnt and new connections are made.

When introducing new material, we need to be careful to ensure that it is not too far removed from what has gone before. There needs to be some degree of 'familiarity'. This does not mean that every worksheet needs to be about something familiar, but ideally material needs to *connect*. If we look at our resources, or plan our explanations, and there are no connections to be made with long-term memory, then the working memory demands will be higher. Tasks which introduce a number of novel elements at once can be a problem.

Take this example from an English lesson:

A class are studying Romeo and Juliet at the start of their GCSE English Literature course. They read the prologue and the teacher wants them to analyse Shakespeare's use of language. In this instance, we have a new play, unfamiliar language to understand, and the introduction of unfamiliar assessment objectives they must address in an essay. It is likely that this will prove challenging. It is a new text; there are lots of new skills; there is a new form of writing. This is not an argument not to teach Shakespeare of course, just a reminder that when introducing lots of new material, working memory demands will be high.

You cannot judge the inherent working memory demands of a task without knowing the context and the pupils. The example above would become less demanding if Shakespeare had been covered before, if pupils had been taught how to write essays, or if they had watched the play beforehand. This text encountered in primary school will be different to someone studying English Literature at A Level.

Complexity

As we increase the number of elements in a task the complexity also increases, and therefore so do the working memory demands.

Any instructions with multiple steps become a challenge for pupils with working memory difficulties. Demands on complexity can be reduced when stages of instructions are familiar or routine. For example, the same series of instructions about packing up for the day will likely be remembered and form part of a repeated sequence. But the more steps that have to be held in working memory, the more likely working memory failure is to occur. Even the way we communicate or phrase instructions can be unnecessarily complex, and sentences with multiple subordinate clauses are harder to follow.

Complexity can be introduced whenever attention is being split, whether in space or in time.

In space

If children have to move back and forth between two sources of information, then working memory demands will be increased, for example, switching between a worksheet and a teacher's whiteboard. This needs to be offset by the fact that children with working memory difficulties will benefit from having memory aids or resources that enable them to reduce the amount of information they have to hold in working memory. For example, a child with working memory difficulties may be allowed to keep a list of the steps to follow when completing a particular mathematical task, when their peers can generally be expected to remember these steps without any prompting. This type of list is an additional source of information, and may therefore introduce some requirement to switch attention. However, keeping these additional sources to hand (e.g., on the pupil's desk, and not on a display board), will help minimise any problems. And the benefit to the child from having the list of prompts available is likely to outweigh any possible issues with split attention. As a rule of thumb, the further apart in space that the sources are, the more that split attention may be problematic.

In time

If too much time elapses between the explanation of a task and the completion of that task, then working memory demands will increase. For example, the pupils are sat on the carpet at the front of the class and the teacher gives instructions about the next task before they return to their seats. During the time taken to go back to their desk, a child with working memory difficulties may have forgotten the instructions.

"What Next?"

Simple questions you can ask:

- What do pupils already know about this?
- Is the information communicated in the simplest terms?
- Are there any significant demands on working memory?

If demands on working memory are likely to be high, then there are a couple of options:

- Reduce the inherent working memory demands of the material.
- Use memory aids, or strategies, to reduce the working memory demands.

As we increase the number of elements in a task the complexity also increases, and therefore so do the working memory demands.

REDUCE THE WORKING MEMORY DEMANDS OF TASKS

To some extent, the recommendations in this section are implicit in the previous section. But sometimes it can be easy to see the problems, whereas finding solutions can be a challenge.

Reduce complexity

Always be very clear about the purpose of the task or the learning sequence, the skill you want them to practice, or the knowledge you want them to learn.

Where there are multiple elements of a task, or multiple instructions, consider whether you can reduce the amount of information given and still maintain the core content. If this is not possible, consider the order in which you present steps, and the amount of information given at any one time. Also consider the design elements of a task which may add unnecessary complexity. Complex fonts, clip art, or even unnecessary colours can be problematic, if they do not serve a clear purpose.

Elements that might prove useful, such as boxes with additional information, may be better introduced in stages, rather than being introduced all at once. There is a tendency to add more in order to support, for example, written explanations to diagrams, but this can sometimes hinder. It's not always easy to judge this, but be mindful of the unintended consequences of too much competing information.

When designing materials, prior knowledge is important. Material will be easier to manage if it connects to what they already know.

Create routines and familiar ways of working

Beyond the task itself, careful planning can go into the classroom environment. This includes the physical environment as well as structures and routines that support learning.

Routines that are made explicit and regularly practised become automatic. And when they are automatic, it frees up working memory to focus on the task at hand. Routines can be about classroom behaviour, resource management, or learning. Learning routines might include routines for managing classroom discussion, writing routines, and instructional routines.

Connect to existing schema

When designing materials, prior knowledge is important. Material will be easier to manage if it connects to what they already know. We should tap into those existing schemas where possible. This is because material that is familiar in long-term memory will place fewer demands when it is retrieved into working memory to be used for the task at hand.

If it cannot be connected to existing schemas, then it may be worth considering whether to change the order in which concepts are taught, and work on building the relevant knowledge that will help pupils to tackle a new task or learning goal.

Further, this knowledge might not just

relate to the topic. Often it can include demands on the format of the task chosen. Imagine that you ask pupils to present their findings on PowerPoint. This might be fine, but if they do not understand PowerPoint then this complicates things. Suddenly a simple requirement to copy and paste an image requires them to manage lots of new information, while still concentrating on the topic-related task. In this case it would be better to teach PowerPoint separately.

Examples, models and analogies can be helpful because they tap into an idea that is familiar. For example, comparing a virus to an invading army, or comparing the earth's shape to an egg, a balloon, or an orange. In each of the examples, we gain by associating with familiar information.

Remove unnecessary processing demands

Think about the clarity of the instructions. Where possible use simple sentences instead of complex ones with multiple clauses. Where there is a task or a key instruction, try to place this first. Consider the following example,

"The goalkeeper was on the six-yard line. The left back was on the goal line. The striker was on the penalty spot when the ball was played through. Was he offside?"

This is easier to process if the key question is placed at the beginning:

"I want you to work out if the striker was offside. The goalkeeper was on the six-yard line. The left back was on the goal line. The striker was on the penalty spot when the ball was played through. Was he offside?"

Time and space

Try to avoid any situation where one thing has to be held in working memory unnecessarily. If elements are in different positions or locations in a classroom, this means some information has to be held in working memory whilst the other relevant information is located. Try to keep information in close proximity, and ideally integrated in one place.

It is the same when there is a split between time. For example, instructions given out when children are sat at the front of class, but have to be completed once they have returned to their desks.

Repeat or model information

The simplest way to respond to a working memory failure is to repeat instructions. This will be particularly important if the task or instructions cannot be modified in other ways.

Teachers can model anything to make it clearer. This could include explicit processes such as writing a description or implicit processes such as choosing the best strategy to answer a maths question. A simple step to help children who are struggling is for the teacher to remodel the process, ideally with another example, but remodelling the initial example may be most appropriate. Copies of models, for example, completed mind maps, act as concrete examples for pupils to refer to, so should be kept visible.

Another way to reduce working memory demands is through the use of memory aids or tools, something that is considered in the next section.

PROVIDE MEMORY AIDS

Children with reduced working memory ability benefit from the ability to offload aspects of task performance on to external memory aids. Transferring some of the processing requirements of a task in this way reduces the demands placed on working memory, releasing capacity to help with successful task completion.

These aids are generally physical or visual aids. For example, it could be a readily available list of French verb endings, the formula for calculating circumference, or a list of sentence starters for a history essay. To aid with calculations, multiplication grids and number lines are simple examples of memory aids, particularly for more complex addition and subtraction.

Many teachers will use classroom displays as a helpful memory aid, but may also have concerns about whether displays themselves may add to distraction. For displays to aid processing, they should be simple, free of too many superfluous elements, and organised effectively so pupils can navigate them. For pupils to 'use' these displays, they need to be taught how.

Principles of clear, uncluttered, simple design will hold for any resource that we create as a memory aid too. Knowledge Organisers, for example, can be used but these again should not be designed in such a way that their use adds to the cognitive demands.

Finally, technology can be used as an aid, for example, voice recording instructions. However, the technology that we want pupils to use should be accessible to all pupils, and pupils may need to be taught how to use it before it can be successfully used to support learning.

When using memory aids that take the place of something that we would ultimately want to be stored in long-term memory (for example multiplication tables), it may be necessary to gradually remove these external aids. Although bear in mind that children with working memory difficulties may struggle when the aids are removed.

It is important that teachers and pupils are aware of the limitations of memory aids. For example, pupils with working memory difficulties may forget how to use the aids effectively, or even forget to use them at all. Without careful use, aids could lead to inflated estimates of our knowledge. For example, if we use a Satnav as a way of offloading cognitive demands, we may be less likely to remember the route. It will get us there and will perform a useful function, in this case to 'take care' of the demands of reading maps and signs, but it will not necessarily mean that we get better at navigation. Using a spell-checker can reduce some of the processing demands of writing, but it will not necessarily improve spelling.

We can gradually remove the memory aids, as the child progresses, for example, remove words from the word wall. Explicitly teach the limitations as part of the initial teaching, for example, explain to the child that when they use the multiplication table, they will not be practising memorising times tables, and this is something that they might still have to do.

TEACH THE USE OF MEMORY-SUPPORTING STRATEGIES

This guide so far has focused on what the teacher can do, but we now want to switch the focus on to the strategies pupils can use to prevent working memory failure or to recover from it.

The teacher still has a role to play in helping pupils to become proficient and confident in using the strategies. Teachers who are aware of working memory limitations, and particular strengths and weaknesses of individual pupils, will be able to target the use of these strategies personally.

Requesting help

'Ask for help' seems a reasonable instruction, but for pupils who are struggling with the working memory demands of a task, it is not simple. First, they must be able to diagnose a problem, then they need to know that seeking help is an appropriate strategy which is likely to be beneficial. Then they must remember to do so.

There are general strategies for seeking help that are quite easily transferable across contexts. For example, asking for instructions to be repeated, asking to be reminded where to find the answers or which page we are on, or asking what to do next. All of these are straightforward approaches which pupils can be encouraged to use through explicit instruction and praise.

Asking for help is difficult when the problem is harder to understand or articulate. Consider giving an explicit reminder before a task that points to sources of help – some of which may be memory aids (as described in the previous section), or may be the teacher, teaching assistant, or partner.

Rehearsing material

If verbal material is required to be remembered for a short period of time, rehearsal can be a useful strategy. This works best for a limited amount of information and can be rehearsed aloud or internally. Although in certain circumstances, for example, a class test, internal might be best!

Rehearsal will not always be an effective strategy, and it will work best when the information is needed immediately; interrupting rehearsal with other activities will lead to forgetting.

Note taking

Note taking is a common strategy in the classroom, but is one that can relieve the working memory demands of a task. It can be as simple as writing down the instructions that the teacher has just given. Other examples include a simple concept map in primary school, or a graphic organiser such as a fishbone diagram in History GCSE.

Keep materials close to hand that can be used for notetaking, or make them easy to access in the classroom with minimal disruption. These might include whiteboards, note-taking templates, digital devices including audio devices, or notebooks.

Using long term memory

Pupils should be encouraged to take advantage of their long-term memory. Information that is securely stored in long-term memory is more familiar, which in turn helps with accessing and processing that information. Also, we create schemas or webs of knowledge within long-term memory for related information. This means that we can then 'chunk' information which in turn frees up some of the capacity of working memory. Chunking can be used to organise lists of information. The most common strategy for this is a simple mnemonic, for example, BIDMAS (order of operations in Maths). Or creating a simple rhyme such as, Divorced; Beheaded; Died; Divorced; Beheaded; Survived (Wives of Henry VIII). When these are repeated regularly, they become part of the pupil's long-term memory, so all they have to think about is one item (BIDMAS), rather than all of them (brackets, indices, division, etc). These examples are well known and can be given to pupils. But there is also benefit in sharing this general strategy with pupils and encouraging them to come up with their own mnemonics which they can use themselves whenever they have to remember items in a longer list.

Despite the potentially limitless capacity of long-term memory, most information from long-term memory that is relevant to the task-at-hand still has to be retrieved into working memory. So, most classroom activities are still constrained by the limits of working memory.

Information that is securely stored in long-term memory is more familiar, which in turn helps with accessing and processing that information.

WORKING MEMORY: WHAT NEXT?

A pdf version of this booklet is available as a free download on the CAER website. In addition, the CAER website provides links to materials that we have developed to help identify children with working memory difficulties, including a behaviour check-list screening questionnaire. The articles referenced in the Research Summary are listed in the Reference Section at the back of this booklet, as well as a Glossary of terms.

We hope that this guide becomes something that you refer to regularly. Having an understanding of the research and considering each of the approaches will ensure that pupils who struggle with working memory can be supported. Remember:

- Recognise and identify working memory problems
- Evaluate working memory demands
- Reduce the working memory demands of tasks
- Provide memory aids
- Teach the use of memory supporting strategies

We are keen to see how teachers and school leaders use the guidance to implement effective approaches in schools. Feel free to contact us via the CAER website.

Professor Amanda Waterman
& Mark Miller

Having an understanding of the research and considering each of the approaches will ensure that pupils who struggle with working memory can be supported.

GLOSSARY

Attention
The cognitive ability to focus on the appropriate, relevant information. Academics sometimes refer to sustained versus divided attention. Sustained attention is the ability to concentrate, over a prolonged period, on the relevant task-at-hand. Divided attention is the ability to switch between different, relevant, sources of information.

Attention Deficit Disorder / Attention Deficit Hyperactivity Disorder
A developmental disorder defined as a persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development.

Backward Digit Recall
A WM test where participants have to remember, and reverse, a sequence of verbally presented digits. Traditionally the experimenter reads out a list of digits (e.g., 5, 1, 8) and the participant then has to repeat them back in the reverse order (e.g., 8, 1, 5). The test consists of many different sequences of digits. The number of digits used in the sequences also increases over the course of the test.

Central Executive
The component in the Multicomponent Working Memory Model that controls the flow of information to and from the phonological loop and the visuospatial sketchpad, and processes and manipulates information.

Chunking
Grouping items of information together. For example, the string of eight digits, 20011977, can be grouped as two chunks, 2001 and 1977.

Cognitive load
In general, this term refers to how much of our cognitive resources are being used up by the task-at-hand. A high cognitive load means that most, or all, of our cognitive resources are being used. A low cognitive load means that we have 'spare' resource that is not currently being used.

Cognitive Load Theory
A specific theory proposed by Sweller based on working memory theory and instructional theory.

Corsi Block Test
A WM test where participants have to remember a visuospatial sequence. It traditionally uses a display of nine randomly, but equally, spaced blocks. The experimenter taps out a spatial pattern using some of the blocks (tapping one block at a time), and the participant then has to tap out the same pattern. The test consists of many different spatial patterns, using a different pattern each time. The number of blocks used to form the spatial pattern also increases over the course of the test.

Decay
The process by which memories can fade (either entirely or partially) or be lost over time.

Episodic buffer
The component in the Multicomponent Working Memory Model that binds information across different modalities (e.g., visual and verbal).

Executive Functions
A set of higher-order cognitive abilities including working memory, planning, decision-making, inhibition, and cognitive flexibility.

Forward Digit Recall
A WM test where participants have to remember a sequence of verbally presented digits. Traditionally the experimenter reads out a list of digits (e.g., 5, 1, 8) and the participant then has to repeat them back in the same order (e.g., 5, 1, 8). The test consists of many different lists of digits. The number of digits used in the lists also increases over the course of the test.

Haptic
Relating to the sense of touch.

Inhibition
The cognitive ability to suppress unwanted or irrelevant behaviours or responses, or to ignore distracting or irrelevant information.

Interference
Where two or more similar memories become confused.

Long-term memory
Memory held over very long periods of time (potentially indefinitely). Potentially limitless storage capacity. But information in long-term memory is still prone to decay or interference.

Multicomponent Working Memory Model
A framework by Alan Baddeley and Graham Hitch that proposes working memory is made up of four separate components. The phonological loop, the visuospatial sketchpad, the central executive and the episodic buffer.

Phonological loop
The component in the Multicomponent Working Memory Model that stores verbal or auditory information.

Refreshing
One of the ways that we can maintain information in working memory.

Rehearsal
One of the ways that we can maintain information in working memory. The most common form is verbal rehearsal, where the information is repeated vocally or sub-vocally.

Short-term memory
Sometimes used interchangeably with Working Memory. But generally used to mean the storage of information, and not the processing or manipulation of information.

Visuospatial Sketchpad
The component in the Multicomponent Working Memory Model that stores visual and spatial information.

Working Memory
The storage and processing of information to help with immediate and on-going cognitive activity. Limited in both capacity and duration.

Working Memory Capacity
The amount of information that can be held in working memory.

Working Memory Duration
The length of time that information can be held in working memory (generally defined as the length of time it can be held without active rehearsal or refreshing).

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Further reading

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