Understanding Working Memory

A Classroom Guide

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Working Memory and Learning

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This booklet provides an introduction to working memory and the role it plays in everyday life, especially in supporting learning in school. The learning difficulties commonly faced by children with very poor working memory skills are described, and are illustrated with case studies. A programme of classroom support for children with working memory problems is outlined.

What is working memory?

Psychologists use the term ‘working memory’ to describe the ability we have to hold in mind and mentally manipulate information over short periods of time. Working memory is often thought of as a mental workspace that we can use to store important information in the course of our mental activities. A good example of an activity that uses working memory is mental arithmetic. Imagine, for example, attempting to multiply 43 and 27 together, and spoken to you by another person, without being able to use a pen and paper or a calculator.

First of all, you would need to hold the two numbers in working memory. The next step would be to use learned multiplication rules to calculate the products of successive pairs of numbers, adding to working memory the new products as you proceed. Finally, you would need to add together the products held in working memory, resulting in the correct solution. Without working memory we would not be able to carry out this kind of complex mental activity in which we have to both keep in mind some information while processing other material.

When do we use working memory?

Mental arithmetic is just one example of an activity that relies on working memory. Other examples from everyday life include:

- remembering a new telephone number, a PIN number, web address or a vehicle registration number while we are trying to find a pen and paper to write it down or to use it in some other way
- following spoken directions such as 'Go straight over at the roundabout, take the second left and the building is on the right opposite the church'
- calculating how much the bill will be at the supermarket checkout for the items we have in our basket
- remembering the unfamiliar foreign name of a person who has just been introduced to you for long enough to enable you to introduce them to someone else
- measuring and combining the correct amounts of ingredients (e.g. rub in 50g of margarine and 100g of flour, and then add 75g of sugar) when you have just read the recipe but are no longer looking at the page.

You may notice from these examples that we typically use working memory as a sort of mental jotting pad in situations when there is no other external record such as written notes or a calculator.

Are there limits to working memory?

Yes. It is unfortunately true that working memory is limited in a number of ways, and can easily fail us when we need it. In particular, we need to continue to pay attention to what is being held in working memory if it is to persist over even short periods of time. Here are some of the situations that often lead to the loss of information from working memory.

- ***Distraction.*** An unrelated thought springing to mind, or an interruption such as a telephone ringing or someone speaking to us, can be sufficient to divert attention the contents of working memory so that its contents are rapidly lost.

- ***Trying to hold in mind too much information.*** There is a limit to how much information can be held in working memory. For example, most of us would not be successful in attempting to multiply the numbers 739 and 891 in our heads, simply because the amount of information that has to be stored in the course of this calculation exceeds the capacity of most people's working memory.

- ***Engaging in a demanding task.*** Activities that require difficult mental processing, such as applying the rules of multiplication during mental arithmetic, reduce the amount of space in working memory to store information. This can result in a loss of other information that is already held.

Once information has been lost from working memory it is gone for good. The only possible way forward is to start again the process of entering information into working memory. In mental arithmetic, for example, the sum would have to be re-calculated from the beginning.

Does working memory capacity vary between people?

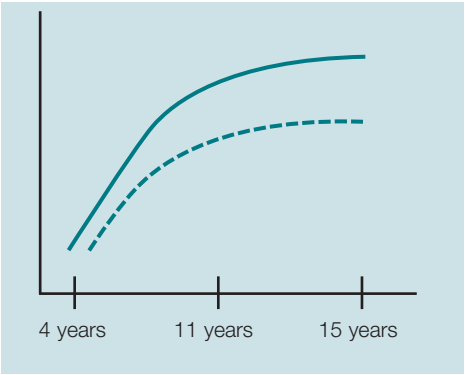
Yes. There is a personal limit to working memory, with each individual having a relatively fixed capacity that may be greater or less than that of others. So, a particular activity may be well within the capacity of one person but exceed that of another.

Working memory capacity also increases with age during childhood. Young children typically have very small capacities that increase gradually until the teenage years, when adult capacities are reached that are more than double that of 4-year-old children. The growth curve of individuals with average and low working memory capacities for their age is shown in the figure overleaf.

Differences in working memory capacity between different children of the same age can be very large indeed. For example, in a typical class of 30 children aged 7 to 8 years, we would expect at least three of them to have the working memory capacities of the average 4-year-old child and three others to have the capacities of the average 11-year-old child, which is quite close to adult levels.

The growth lines on the figure also show that, typically, individuals who have poor working memory capacities in childhood do not catch up with those of their peers. Although their working memory capacities increase with age, they do not do so at the same rate as other individuals so that, as they grow older, they lag behind more or more.

Changes in working memory capacity with age



The changes in working memory capacity with age for an average child are shown by the solid line. Scores of a child with a low working memory capacity are represented by the broken line.

Why is working memory important in classroom learning?

Many of the learning activities that children are engaged with in the classroom, whether related to reading, mathematics, science, or other areas of the curriculum, impose quite considerable burdens on working memory. Activities often require the child to hold in mind some information (for example, a sentence to be written down) while doing something that for them is mentally challenging (such as spelling the individual words in the sentence). These are the kinds of activities on which children with poor working memory struggle with most, and often fail to complete them properly because they have lost from working memory the crucial information needed to guide their actions. As a result, the children may not get the learning benefit of successfully completing an activity, and this slows down their rates of learning.

Children with poor working memory also have problems following lengthy instructions to do one thing after another, because they forget the instruction before the whole sequence of actions has been completed. As a consequence, the child will often not engage properly with the normal pace of ongoing classroom activities. Often it appears that the child has not paid attention, when in fact they have simply forgotten what it is that they have to do.

Working memory is also needed to help us remember where we have got to in a complicated mental activity. Consider the case of a child with low working memory capacity attempting to follow the teacher's instructions to write down a sentence she has just spoken. The child not only needs to hold the sentence in working memory for sufficiently long to guide his or her attempts to write the individual words, but needs to remember how far they have got in this attempt, and to find the next word in working memory. Although to skilled writers this seems like an easy task, children with poor working memory capacities find this extremely difficult, and often either skip or repeat words and letters as they lose their place in this demanding mental activity.

Characteristics of children with poor working memory

Typically, children with poor working memory:

- are well-adjusted socially
- are reserved in group activities in the classroom, rarely volunteering answers and sometimes not answering direct questions
- behave as though they have not paid attention, for example forgetting part or all of instructions or messages, or not seeing tasks through to completion
- frequently lose their place in complicated tasks that they may eventually abandon
- forget the content of messages and instructions
- make poor academic progress during the school years, particularly in the areas of reading and mathematics
- are considered by their teachers to have short attention spans and also to be easily distracted.

What is the cause of low working memory?

Why some children have poor working memory capacity is not yet well understood. It is, however, known that low working memory is not strongly related to factors relating to the child's background, such as inadequacies in pre-school experiences or education, or with the quality of social or intellectual stimulation in the home. It seems likely that genes play an important role in the frontal areas of the brain that support working memory.

How can working memory be measured?

There are several methods that can be used to measure the working memory capacity of children. These methods are suitable for use with children from about 4 years of age, and typically involve the child attempting to both store and manipulate information in mind over brief periods of time.

Individual tests take no longer than five minutes to administer. Paper and pencil tests are available in the *Working Memory Test Battery for Children*, which is standardised for children aged 4 to 15 years. We have also developed a simple PC-based program called the *Automated Working Memory Assessment (AWMA)* that can be used from 4 to 22 years. The AWMA is designed for easy administration for classroom teachers and other professionals working in the fields of education, medicine, and health. Test scores are calculated automatically by the computer program, and the child's performance is automatically summarised at the end of testing. Use of this test requires little training, and was developed primarily for classroom use. Both the *Working Memory Test Battery for Children* and the *Automated Working Memory Assessment* can be purchased from Harcourt Assessment (www.harcourt-uk.com).

To help teachers identify children who are at risk of having working memory problems without administering direct tests of memory, the *Working Memory Checklist for Children* has recently been developed. This is a rating scale on which teachers judge how frequently a child exhibits problem behaviours associated with poor working memory. A high score on this checklist indicates that a child is likely to have working memory problems that will affect their academic progress. The *Working Memory Checklist for Children* is also available from Harcourt Assessment: www.harcourt-uk.com.

Working memory and learning difficulties

Poor working memory capacity is characteristic of children with many kinds of learning difficulties. These include individuals with language impairments, with difficulties in reading and mathematics (including dyslexia), with some forms of ADHD and with developmental coordination disorder. Approximately 70% of children with learning difficulties in reading obtain very low scores on tests of working memory that are rare in children with no special educational needs.

Not all children with special educational needs have working memory problems. Individuals with problems in areas that are not directly related to learning, such as emotional and behavioural disturbances, typically have working memory capacities that are appropriate for their ages.

Why is working memory crucial for learning?

Working memory is important because it provides a mental workspace in which we can hold information whilst mentally engaged in other relevant activities. The capacity to do this is crucial to many learning activities in the classroom. Children often have to hold information in mind whilst engaged in an effortful activity. The information to be remembered may, for example, be the sentence that they intend to write while trying to spell the individual words. It could also be the list of instructions given by the teacher while carrying out individual steps in the task.

Children with small working memory capacities will struggle in these activities, simply because they are unable to hold in mind sufficient information to allow them to complete the task. In these situations, their working memory is overloaded. Losing crucial information from working memory will cause them to forget many things: instructions they are attempting to follow, the details of what they are doing, where they have got to in a complicated task, and so on.

Because children with poor working memory fail in many different activities on many occasions due to working memory overload, they are likely to struggle to achieve normal rates of learning and so will typically make poor general academic progress.

For such children, we recommend an educational approach in which the teacher monitors the child's classroom learning activities and modifies them if necessary in order to ensure that he or she is working within their working memory capacity rather than being overloaded. This will help the child to complete and succeed in these activities, and so will build up knowledge and skills across time in a way that will facilitate learning. More detailed guidance about this approach is provided in the 'Classroom support for children with working memory problems' section.

Case study of a child with poor working memory

Nathan is a 6-year-old boy with an impairment of working memory. His non-verbal IQ is in the normal range. He is a quiet child who is well-behaved in the classroom, and is relatively popular with his peers. He has been placed in the lowest ability groups in both literacy and numeracy. His teacher feels that he often fails to listen to what she says to him, and that he is often 'in a world of his own'.

In class, Nathan often struggles to keep up with classroom activities. For example, when the teacher wrote on the board 'Monday 11th November' and, underneath, 'The Market', which was the title of the piece of work, he

lost his place in the laborious attempt to copy the words down letter by letter, writing 'moNemarket'. It appeared that he had started to write the date, forgotten what he was doing and began writing the title instead. He also frequently fails to complete structured learning activities. In one instance, when his teacher handed Nathan his computer login cards and told him to go and work on the computer numbered 13, he failed to do this because he had forgotten the number. On another occasion, Nathan was encouraged to use a number line when counting the number of ducks shown on two cards but struggled to coordinate the act of jumping along the line with counting up to the second number. He abandoned the attempt, solving the sum instead by counting up the total number of ducks on the two cards.

Nathan also has difficulty with activities that combine storage of multiple items with other demanding mental processing. For example, when asked to identify two rhyming words in a four-line text read aloud by the teacher, Nathan was unable to match the sound structures of the pair of words, store them and then recall them when the teacher finished reading the text.

Classroom support for children with working memory problems

As yet, no certain ways of directly improving working memory in children such as Nathan have been developed. However, there is plenty that can be done to enhance learning in children with working memory problems. The approach that we recommend involves teachers managing children's working memory loads in the classroom, with the aim of alleviating the disruptive consequences on learning of excessive working memory loads.

The following recommendations should be used to guide both the development of lesson plans for children with working memory impairments and the monitoring of children's performance in class. In each case, the aim is to minimise the chances that the child will fail to complete the intended learning activity successfully due to working memory failures.

1. Recognise working memory failures

Working memory failures typically manifest themselves in frequent errors of the following kinds:

- incomplete recall, such as forgetting some or all of the words in a sentence, or of a sequence of words
- failing to follow instructions, including remembering only the part of a sequence of instructions, or forgetting the content of an instruction (for example, the child correctly remembers to go to Mrs Smith's classroom as instructed by the teacher, but once there cannot remember the content of the message to be given)
- place-keeping errors – for example, repeating and/or skipping letters and words during sentence writing, missing out large chunks of a task
- task abandonment – the child gives up a task completely.

If these types of activity failure are observed, it is recommended that the working memory demands of the task are considered (see point 2) and if believed to be excessive, the activity should be repeated with reduced working memory loads (see point 3).

2. Monitor the child

It is important to monitor the child's working memory regularly in the course of demanding activities. This will include:

- looking for warning signs of memory overload (see point 1);
- ask the child directly – for example, ask for details of what s/he is doing and intends to do next.

In cases when the child has forgotten crucial information:

- repeat information as required
- break down tasks and instructions into smaller components to minimise memory load
- encourage the child to request information when required.

3. Evaluate the working demands of learning activities

Activities that impose heavy storage demands typically involve the retention of significant amounts of verbal material with a relatively arbitrary content. Some examples of activities with working memory demands that are likely to exceed the capacities of a child with working memory deficits include:

- remembering sequences of three or more numbers or unrelated words (e.g. *5, 9, 2, 6* or *cat, lion, kangaroo)*
- remembering and successfully following lengthy instructions (e.g. *Put your sheets on the green table, arrow cards in the packet, put your pencil away, and come and sit on the carpet)*
- remembering lengthy sentences containing some arbitrary content to be written down (e.g. *To blow up parliament, Guy Fawkes had 36 barrels of gunpowder)*
- keeping track of the place reached in the course of multi-level tasks (e.g. writing a sentence down either from memory or from the white board)

4. Reduce working memory loads if necessary

In order to avoid working-memory-related failures (see point 1), working memory loads in structured activities should be decreased. This can be achieved in a number of ways, including:

- reducing the overall amount of material to be stored (e.g. shortening sentences to be written or number of items to be remembered)
- increasing the meaningfulness and degree of familiarity of the material to be remembered
- simplifying the linguistic structures of verbal material (e.g. using simple active constructions rather than passive forms with embedded clauses in activities involving remembering sentences, and in instructions)
- reducing processing demands (see point 5)
- re-structuring multi-step tasks into separate independent steps, supported by memory aids if possible
- making available and encouraging the use of external devices that act as memory aids for the child; these include ‘useful spellings’ on white boards and cards, providing number lines, printed notes, and dictaphones to store information that needs to be remembered.

5. Be aware that processing demands increase working memory loads

Although children may be capable of storing a particular amount of information in one situation, a demanding concurrent processing task will increase working memory demands and so may lead to memory failure, as illustrated in the two examples below of children with working memory deficits.

Example 1

The children in Nathan's class were asked to identify the rhyming words in a text read aloud by the teacher. They had to wait until all four lines had been read before telling the teacher the two words that rhymed: tie and fly. This task involves matching the sound structures of a pair of words, and storing them. Nathan was unable to do this, although he was able to remember two words under conditions where no concurrent processing was required.

Example 2

An activity in Jay's class involved the teacher writing number sequences on the white board with some numbers missing. She counted the numbers aloud as she wrote them, and asked the class what numbers she had missed out. In each case, there was more than one number missing (e.g. 0, 1, 2, 4, 5, 7, 8). In this activity, the child has to use his/her number knowledge to identify each missing number, and store them. On all occasions, Jay was unable to identify the missing numbers.

In such cases, steps should be taken to modify the learning activity in order to reduce working memory loads (see point 3).

6. Frequently repeat important information

It is good practice when working with children with working memory deficits to regularly repeat information that is crucial to ongoing activities. This will include:

- general classroom management instructions
- task-specific instructions (what the whole activity consists of, broken down into simple steps)
- detailed content intrinsic to an activity (e.g. the particular sentence to be written).

Children should also be encouraged to request repetition of important information in cases of forgetting.

7. Encourage the use of memory aids

A variety of tools that support memory are in common use in classrooms – these include number lines, Unifix blocks and other counting devices, cards, dictaphones, personalised dictionaries with useful spellings, teacher notes on the class white board, and wall charts. These tools can help in several different ways to reduce working memory loads – they may reduce the processing demands of the activity (e.g. useful spellings and Unifix blocks), and they may also reduce the storage load of the task and so help the child keep their place (e.g. number lines).

However, many children with working memory problems often struggle to use such tools, possibly because of the initial cost of mastering the new skill. It is therefore recommended that children are given practice in the use of memory aids in situations with minimal working memory demands in order to establish mastery of the basic skill, before their use in more complex activities with higher working memory loads.

8. Develop the child's use of memory-relieving strategies

Children with working memory deficits are typically aware of when they have forgotten crucial information, but often do not know what to do in such situations. An important role for the teacher is to encourage the child to develop strategies for overcoming memory problems. These will include:

- use of rehearsal to maintain important information
- use of memory aids (see point 7)
- organisational strategies – breaking tasks down into component parts where possible
- asking for help when important information has been forgotten.

Teachers' experiences of using this intervention

We have applied the following principles in primary schools across the UK to help teachers identify both strengths and weaknesses in students and to provide intervention strategies that minimise learning difficulties. Feedback from teachers indicates that the intervention strategies were easy to implement in the classroom. They also noted improvements in the whole class as a result of the intervention, such as improved concentration and focus, as well as increased ability to follow instructions. Here are some comments that teachers have made.

Stephen is much better at following instructions when they are broken down into simple steps.

The basic understanding of the 'critical' nature of memory problems is essential for teachers, also the understanding of, once forgotten, the information cannot be retrieved.

Sarah will now independently ask for information to be repeated or ask for help when required. Before, she used to sit there and look very confused but not ask for support.

We've always had memory aids available in the classroom but the pupils tended not to automatically use them. I've spent a lot of time recently demonstrating how to use them as support tools within my teaching and the pupils now use them independently and effectively.

I've noticed an improvement in the child's self-esteem over the last few weeks as the strategies help her to participate more fully in lessons and remain on task.

We've been concerned about Liam for a long time but could never quite pinpoint the problem. It's good to see him responding well to some of the strategies, particularly with regards to breaking down instructions and tasks into smaller, more manageable steps.

I use most of the strategies in my everyday teaching but I've noticed a big improvement in attention, behaviour and standard of work since directing them specifically towards Jessica.

Ben has made good progress over the last few weeks. He still has a long way to go but at least he remains on task now and is beginning to achieve rather than abandoning tasks as he often used to.

I've noticed similar characteristics in other pupils in the class/school. It would be interesting to have them assessed to see if they also have low working memories.

Frequently-asked questions about intervention

Do I have to change what I teach, and plan different learning activities for this child?

You do not need to change the way the curriculum is delivered in any way to use this approach effectively. One of the benefits of this approach is that teachers do not need to change the content of what they teach. The strategies that form the intervention are simply ways of ensuring that within regular classroom activities, the child is not placed in situations where he or she is not able to remember what they are doing or the more detailed content of the task.

I have a child in my class who is making very slow progress, but as far as I know does not have a particular problem with working memory. Would there be any problem in trying out this intervention for him?

If this child is frequently failing during structured learning activities, it would definitely be worthwhile to apply the principles of the intervention and finding out whether his or her performance improves when working memory loads are reduced. This approach will not harm anyone, and you will be able to judge for yourself whether you are seeing any improvements and so whether it is worth continuing.

If you wish to investigate more systematically whether this child has a working memory problem, you should consider either completing the *Working Memory Checklist for Children*, a behaviour rating scale devised for use by teachers, or the *Automated Working Memory Assessment*, a PC-based direct assessment of working memory. More information on these measures is provided in the section 'How can working memory be measured?'

I already incorporate many, if not all, of the features of the intervention approach in my teaching. Is it anything new?

This approach combines many elements of good teaching practice, and many teachers employ some or all of these strategies instinctively. What we are suggesting is that putting together all of these ways of preventing the child's memory from being overloaded will substantially increase their chances of successful learning.

About the authors

Professor Susan Gathercole is a psychologist with over 20 years of experience in research on memory during childhood. She has written many articles for psychologists and teachers, is a founding co-editor of the journal *Memory*, and has developed several standardised tests of memory for children. Susan is a Professor of Psychology at the University of York.

Dr Tracy Packiam Alloway is a research psychologist in the School of Education at the University of Durham. She has worked with educational professionals, including educational psychologists, learning support co-ordinators, head teachers, and classroom teachers in her research on working memory and learning. She is the author of numerous academic articles and books on how children learn. Furthermore, she has developed a computerised screening tool for working memory impairments that has been translated into 10 languages.

Professor Gathercole and Dr Alloway are both members of the Centre for Working Memory and Learning at the Universities of York and Durham. Further information and resources are available from the Centre website on **http://www.york.ac.uk/res/wml/**

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