# Understanding Working Memory
## 2nd Edition

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CHAPTER 1

# OUR BRAIN'S POST-IT NOTE

This chapter looks at:

- WHAT is working memory?
- WHERE is working memory in the brain?
- WHY is working memory linked to learning?

My (Tracy's) journey began, on a crisp October day about 10 years ago.

I was surrounded by a sea of small and eager faces, the children all in neatly pressed uniforms. As part of a government-funded project, I was working with kindergarteners to understand what cognitive skills are important for academic success.

I met Andrew that day. That 6-year-old boy stood out from the rest. He loved being at school and made friends quickly. In the classroom, he was always excited about participating and would raise his hand to answer questions. Andrew enjoyed 'story time' best, when Mrs Smith would ask the children to present a short story. Andrew loved telling stories and would be so animated and use such creative examples that all the children enjoyed them as well.

As the school year progressed, I noticed that Andrew began to struggle with daily classroom activities. He would often forget simple instructions or get them mixed up. When all the other children were putting their books away and getting ready for the next activity, Andrew would be standing in the middle of room, looking around confused. When Mrs Smith asked him why he was standing there, he just shrugged his shoulders. She tried asking him to write down the instructions so he could remember what to do. But by the time he got back to his desk, he had forgotten what he was supposed to write down.

His biggest problem seemed to be in writing activities. He would often get confused and repeat his letters. Even spelling his name was a struggle, he would write it with two 'A's or miss out the 'W' at the end. Mrs Smith tried moving him closer to the board so he could follow along better. This didn't seem to work; he would still get confused.

Mrs Smith was at a loss. She always had to repeat instructions to Andrew but he never seemed to listen. It was as if her words went in one ear and out the other. On another occasion an assistant found him at his desk not working. When she asked him why he wasn't doing the assignment, he hung his head and said, 'I've forgotten. Sometimes I get mixed up and I am worried that teacher will get angry at me.'

His parents contacted me to see if I could help. They were concerned that Andrew might have a learning disability. When I tested Andrew on a range of psychological tests, I was surprised to find that he had an average IQ. Yet, by the end of the school year, he was at the bottom of the class.

Two years later, I went back to the school to conduct some follow-up testing on the children. Andrew seemed like such a different boy. He was placed in the lowest ability groups for language and math. He became frustrated more easily and would not even attempt some activities, especially if they involved writing. His grades were poor and he often handed in incomplete work. He only seemed happy on the playground.

Although I wasn't able to follow up on Andrew, I never forgot him. His predicament inspired me to deeply research how we can support thousands of students who, like Andrew, struggle in class through no fault of their own. This book is about a powerful cognitive skill called working memory that, when properly supported, can stop students like Andrew from remembering their school years as a frustrating experience.

## A foundational classroom skill

It is hard to conceive of a classroom activity that does not involve working memory – our ability to work with information. In fact, it would be

impossible for students to learn without working memory. From following instructions to reading a sentence, from sounding out an unfamiliar word to calculating a math problem, nearly everything a student does in the classroom requires working with information. Even when a student is asked to do something simple, like take out their science book and open it to page 289, they have to use their working memory. They have to work with a number of pieces of information, including looking for the book in the right place, such as recalling that it is in their desk and not in their backpack, identifying which book is in fact their science book, and finally guesstimating where among the thick stack of pages they are most likely to find the correct one. If they overestimate or underestimate, they have to use their working memory to adjust, and flip forwards or backwards until they finally find page 289.

Most children have a working memory that is strong enough to quickly find the book and open to the correct page, but some don't – approximately 10% in any classroom. A student who loses focus and often daydreams may fall in this 10%. A student who isn't living up to their potential may fall in this 10%. A student who may seem unmotivated may fall in this 10%. In the past, many of these students would have languished at the bottom of the class, because their problems seemed insurmountable and a standard remedy like extra tuition didn't solve them. But emerging evidence shows that many of these children can improve their performance by focusing on their working memory. Working memory is a foundational skill in the classroom and when properly supported it can often turn around a struggling student's prospects.

## WHAT: What is working memory?

One way to think of working memory is as the brain's 'Post-it note'. We make mental scribbles of what we need to remember. In addition to remembering information, we also use working memory to process or manage that information, even in the face of distraction. In a busy classroom, with classmates talking, pencils dropping, and papers rustling, the student has to use their working memory to ignore the activity around them and focus on what they need to accomplish.

Working memory is critical for a variety of activities at school, from reading comprehension and math to copying from the board and navigating around school. In the classroom, we use **verbal working memory** to remember instructions, learn language, and complete reading comprehension tasks. **Visual–spatial working memory** is linked to math

skills and remembering sequences of patterns, images, and locations. Below are specific examples of activities requiring working memory taken from real classrooms.

## Classroom activities that involve verbal working memory

- Remembering and carrying out lengthy instructions. Here is an example from a classroom of 6-year-olds: *Put your sheets on the green table, put the arrow cards in the packet, put your pencil away, and come and sit on the carpet*. Students with poor working memory are usually the first ones to sit down on the carpet – because they carried out only the first part of the instruction but forgot the rest!
- Remembering and writing down text, including words, sentences, and paragraphs.
- Remembering word lists that sound similar (example: *mat*, *man*, *map*, *mad*).
- Remembering sentences with complicated grammatical structure, such as *To save the princess, the knight fought the dragon*, which is harder to understand than *The knight fought the dragon* ***to save the princess.***

## Classroom activities that involve visual–spatial working memory

- Solving a mental math problem.
- Keeping track of their place when writing a sentence from the board. The student with poor working memory will often repeat or skip letters.
- Using pictures or images to retell a story. The student with poor working memory may get confused about the order of events in the story or even leave out key events.
- Identifying missing numbers in a sequence: *0*, *1*, *2*, __, *4*, *5*, __.

## Working memory versus short-term memory

Working memory is distinct from short-term memory, which lets you remember information for a brief time, usually a few seconds. Students use short-term memory when they look at something on the board, like 42 + 18, and remember it long enough to write it down. But they use their working memory to solve the problem, for example, by adding 40 to 10, holding 50 in mind, next adding 2 to 8, and adding both answers to get 60. Think of working memory as **'work'**-ing with information to remember.

### Working memory versus long-term memory

Working memory is also distinct from long-term memory. For a student, long-term memory includes the library of knowledge they have accumulated in the course of their academic career. This may be math facts ($6 \times 4 = 24$), spelling rules ('i' before 'e' except after 'c'), scientific and historical knowledge, or the different sounds that phonemes make. Working memory is like a librarian who pulls the appropriate knowledge out of their library when it is needed. For example, if you ask a student to name the first president of the United States, it is their working memory that searches through their long-term memory and finds 'George Washington'.

### Try It: Verbal working memory 

Read these sentences and decide if they are true or false:

1. Bananas live in water: true or false?
2. Flowers smell nice: true or false?
3. Dogs have four legs: true or false?

Now, without looking at those sentences, can you remember the last word in each sentence in the correct order? If you were able to remember them, congratulate yourself. Your working memory is like that of an average 7-year-old. This test is an example of the Listening Recall test from the Automated Working Memory Assessment. It measures verbal (auditory) working memory.

In this book, **verbal working memory** is synonymous with **auditory working memory**. In tests like this, the sentences are presented verbally and the student repeats the information out loud. In Chapter 2, we look at standardized tests to identify working memory deficits.

## WHERE it is: Working memory and the brain

Brain imaging has confirmed that when we perform working memory tests, like the one in the Try It box, there is activity in the prefrontal cortex (PFC). The PFC also works with other areas of the brain when we use working memory. For example, when we engage in visual–spatial activities like navigating to a new restaurant, the hippocampus (the home of spatial information) is activated as our working memory draws on it to determine where we currently are, and where we need to go. When we engage in verbal information, like answering questions in a job interview,

our working memory draws on 'language centers' such as Broca's area, in order to craft an appropriate response.

## Working memory growth

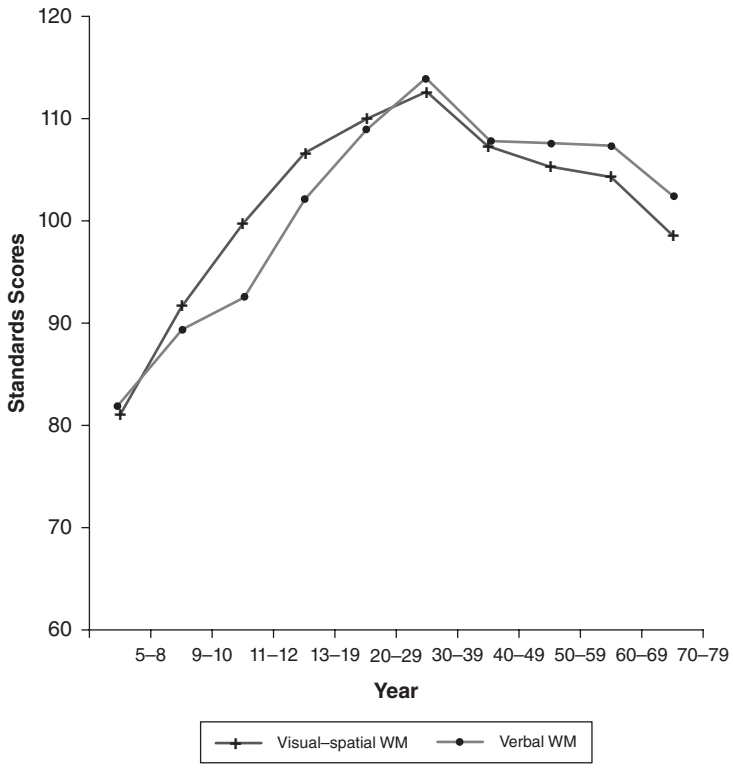


**Figure 1.1** Working memory growth

Working memory growth is closely aligned with the development of the prefrontal cortex. We conducted a study with hundreds of participants from 5 to 80 years old to find out more about how working memory grows at each age (Figure 1.1). The most dramatic growth is during childhood – working memory increases more in the first 10 years than it does over the lifespan. There is also a steady increase in working memory capacity up to our thirties. At this point, working memory reaches a peak and plateaus. The average 25-year-old can successfully remember about five or six items. As we get older, working memory capacity declines to around three to four items.

The amount of information that working memory can process at each age has important implications for the classroom. A teacher attending a

seminar Tracy gave in Seattle commented that she now understood why her class found it difficult to complete what she asked them to do. Here is an example of instructions she had given to her class: *Put your notebooks on the table, put colored pencils back in the drawer, get your lunchbox, and make a line by the door.* Instead of forming neat lines by the classroom door after putting away their books, they would wander around the class. 'I know why now: I would always give them four things to do at a time and it was too much for their working memory', she said after learning about the average space we have in our working memory at each age. Here is a quick guide for tailoring classroom instructions for working memory capacity at different ages:

- 5–6 years: 2 instructions
- 7–9 years: 3 instructions
- 10–12 years: 4 instructions
- 13–15 years: 5 instructions
- 16–29 years: 6 instructions

Up until our thirties, working memory is constantly increasing in size. It is getting bigger, which means we can process more information on our mental Post-it note. But some people's working memory grows faster than others. Think of a 7-year-old with a high working memory. Imagine a 10-year-old in a class of 7-year-olds. They are bored with what the teacher is saying and they finish assignments before anyone else. They may even act out because they have nothing else to do. This is exactly what it is like for a student with a higher working memory than his or her peers. About 10% of your class will fall in this group.

Let's look at the other end of the scale – the student with a poor working memory. Now imagine a 4-year-old in that class of 7-year-olds. They would be frustrated like the 10-year-old, but for the opposite reason: lessons are too hard to understand so they give up trying. The teacher is talking too fast for them to keep up; they can't spell all the words he or she is saying; they are struggling with adding up the numbers in the math problems; and they can't read the required text. Students with poor working memory often struggle in classroom activities because they are unable to hold in mind all the necessary information to complete the activity. As a result, they will disengage from learning.

## WHY working memory predicts grades

Working memory is so important for learning that by knowing a student's working memory we can predict their grades throughout their academic

career. As part of a large government-funded study (Alloway et al., 2006), hundreds of kindergarteners (5- to 6-year-olds) were tracked over a 6-year period and it was found that the children with high working memory did well in reading, writing, and math; while those with low working memory struggled in these tasks. Six years later, these students were tested again and their working memory ability at 5 years old was shown to determine how well they performed in standardized assessments of reading and math (Alloway and Alloway, 2010).

Think about your classroom. Some students perform better than others. Why is it so easy for the girl sitting in the front, but so hard for the student to her right? They all sit through the same lesson, yet have very different results. To answer this question, a group of 8- to 11-year-olds with learning disabilities were tracked over a 2-year period (Alloway, 2009). Even though they were receiving extra educational support, like tutoring and special classes, they were still performing at the bottom of the class. Their learning outcomes had not improved and they were still struggling. Students also became more frustrated and this was manifested in behavior problems. Why didn't they show any improvement? A closer look at their working memory scores revealed that all of them had low working memory scores and their working memory deficits meant that they could not fully absorb the information. It was like entering a bike race with flat tires: without any support for their working memory, they weren't able to make much progress in their learning.

## Working memory and IQ

IQ is not nearly as reliable as working memory in predicting grades. This finding is important as it suggests that IQ, still viewed as a key predictor of academic success, is not a useful benchmark of success. An individual can have an average IQ score but perform poorly in learning, as we saw with Andrew at the beginning of this chapter. This is because IQ tests measure knowledge that students have already learned. If students do well on one of these tests, it is because they know the information they are tested on.

A commonly used measure of IQ is a vocabulary test. If they know the definition of a word like *bicycle* or *police*, then they will likely get a high IQ score. However, if they don't know the definitions of these words or perhaps don't articulate them well, this will be reflected in a low IQ score. In this way, IQ tests are very different from working memory tests because they measure how much students know and how well they can articulate this knowledge.

IQ test scores are strongly driven by a child's background and experiences. One research project involved two different schools: one was in an urban, developed area, while the other was in an underprivileged neighborhood (Alloway et al., 2014). As part of the project, students' IQ skills were tested using a vocabulary test. One of the vocabulary words – *police* – drew very different responses. Students from the urban school provided definitions relating to safety or uniforms, which corresponded to the examples in the manual. However, those from the underprivileged neighborhood responded with statements like *I don't like police* or *They are bad because they took my dad away*. Although both responses were drawn directly from the children's experiences, only one type of answer matched the IQ manual's definitions.

Working memory is a better predictor of success than IQ because it measures a student's **potential to learn.** A common working memory test is to remember a sequence of numbers in the reverse order that it was presented to you. If students struggle in this test, it is not because they don't know how to count, or don't understand number magnitude. It doesn't even matter whether they can recognize the numbers. If they struggle in this working memory test, it is often because their mental 'Post-it note' isn't big enough to remember three or four numbers. Working memory is a better predictor of success than IQ from kindergarten to college because it measures students' ability to learn, rather than what they have learned.

### Science Flash: Working memory and impulse control

Working memory is also linked to a very important skill: impulse control. In a series of well-publicized studies from the 1960s, Stanford psychologist Walter Mischel offered more than 600 children between the ages of 4 and 6 a marshmallow. Then he told them that he was going to leave the room, and if they could wait until he returned, they would get a second marshmallow. If they could not wait, they could ring a little bell that he left on the table, and he would return and let them eat the one marshmallow. Some of the children immediately popped the marshmallow into their mouths while others resisted temptation and held out for the greater reward of two marshmallows. Resisting the temptation to eat the marshmallow involves working memory as the children had to come up with a plan to distract themselves from the thought of eating the marshmallow.

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Mischel tracked these children over the years and found that their ability to control their impulses played an important role later in life. For example, in a 1990 follow-up study, children who had better impulse control and waited for that second marshmallow had higher scores in a standardized achievement test (SAT). He also tested them as adults and put them in a brain scanner while they were performing cognitive tasks involving impulse control. He found that the adults who had resisted the marshmallow temptation as children were more likely to show activation in their prefrontal cortex, the home of working memory, while they were performing a similar impulse control as adults. However, the adults who were not able to resist the marshmallow temptation as children did not show activation in the prefrontal cortex. Working memory is an important cognitive skill that we use to control our impulses and make good decisions, which can help us achieve our long-term goals.

## Working memory deficits

Ben walks through the door, nervous and dreading the moment when his mother is going to ask the question he knows is coming: 'Can I see your report card?' He takes it out of his backpack with sweaty hands. His mother reads the results of a semester's worth of work, and sighs, 'We'll try harder next time'. Unfortunately, trying harder isn't going to make a difference. Many students like Ben try hard every day and still struggle.

Students like Ben haven't been diagnosed with a learning disorder, though they have lower grades. Often when a student is performing poorly, teachers and psychologists look for evidence of a particular problem, like ADHD or dyslexia. When the evidence isn't found, the student is often misunderstood as 'lazy' and unwilling to put in the effort necessary for success. It is important to recognize that many of these students have a poor working memory, and no amount of effort is going to improve their grades if their working memory isn't supported.

Working memory affects all areas of learning, from language to math, from history to art. No matter how hard Ben tries, he will not 'catch up' with his peers. If a child has low grades in kindergarten as a result of their working memory, they will almost certainly have poor grades all the way through high school. One study (Alloway, 2009) found that teenagers who had been diagnosed with working memory deficits two years previously were still performing very poorly in school.

As students get older, the learning gap widens and they will continue to struggle throughout their academic career. A struggling 6-year-old with working memory deficits is unlikely to catch up with peers without intervention . A government-funded study comparing 6- and 11-year-olds with working memory deficits found that the effect of poor working memory is cumulative, resulting in greater decrements in learning as a student gets older (Alloway et al., 2009).

This difference in performance can be explained in part by the classroom environment of the two age groups. Younger children are more likely to have additional adult support and memory aids made available for them in the classroom. However, as they get older, they are typically expected to be more independent in their learning and may be left to develop their own strategies. Among older students, teachers are also more likely to use longer and more complex sentences, which require the students to rely on their working memory. Their poor working memory means that they struggle to acquire key learning skills and concepts. Without these building blocks in place, they are unable to keep up with their peers. As they get older, the combination of the increasing difficulty of their class work and an insufficient learning foundation results in them lagging behind their peers.

This is why early diagnosis and support is so crucial. It is not unusual to encounter parents of college-age students who with tears in their eyes say how they wished they had known about working memory when their child was younger, how much it could have helped them, and how much they struggle just to pass a test now they are in college. The good news is that we can change their grades by changing their working memory.

## Working memory and learning disabilities

Some students have poor working memory and a learning disability as well. In fact, if a student has a learning disability, they also have a poor working memory. Thus students with learning disabilities have a **double deficit**: they have a 'core problem' and a working memory deficit. Each of the learning disabilities included in this book has a very different 'core problem'. For example, students with dyslexia are characterized by reading difficulties; those with dyscalculia struggle with math; students with developmental coordination disorder (DCD) have motor impairments, those with ADHD find it hard to inhibit and control their behavior, individuals with autistic spectrum disorder have a restricted range of language and social skills; and those with an anxiety disorder can experience a working memory overload due to worrisome thoughts.

Given their distinctive profile, what do these groups have in common? All of them have a weakness in working memory (Figure 1.2). That is not to say that poor working memory causes the core deficit in their respective disorder. However, it coexists as a separate problem and ultimately leads to learning difficulties. For example, a deficit in working memory does not cause motor problems in the student with DCD, but their weak working memory leads to learning difficulties (Chapter 5). Throughout this book, we will learn that each group has a specific area of working memory strength and weakness, and when we know what this is, we can provide targeted support to maximize learning.

Each disorder included in this book – reading and math disabilities, DCD, ADHD, autistic spectrum disorder, and anxiety disorders – appears in some form in the *Diagnostic and Statistical Manual of Mental Disorders* (now in its fifth edition and known as *DSM-5,* APA, 2013). This volume, published by the American Psychiatric Association, is the

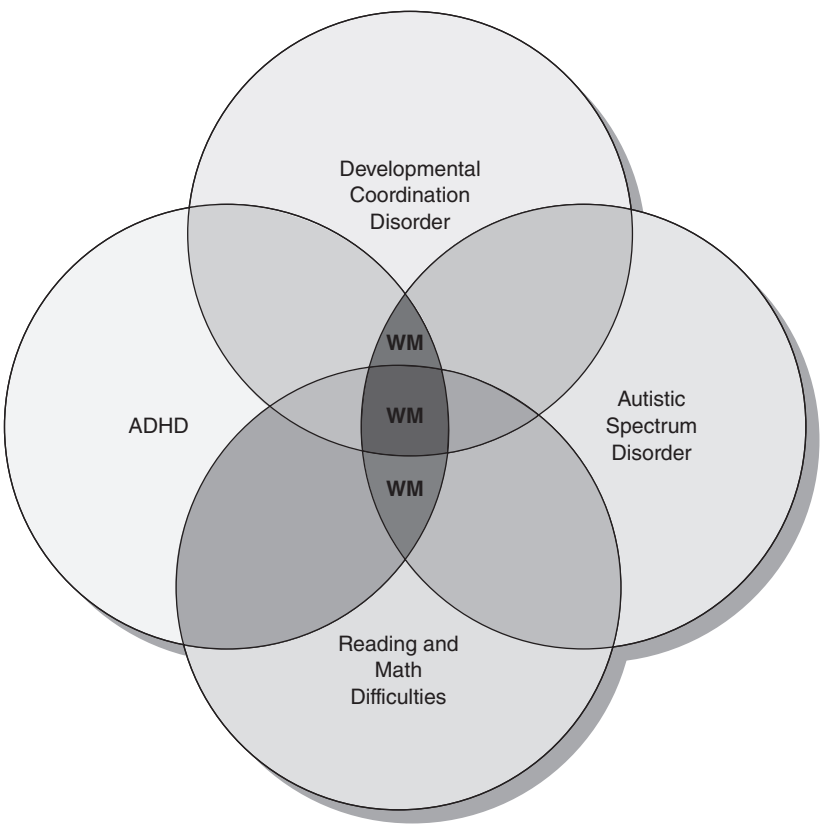


**Figure 1.2** Learning disorders

leading reference manual for disorders, and the diagnostic criteria provide a valuable and trusted resource used by clinicians, researchers, and related professionals around the world. Inclusion in *DSM-5* goes some way in validating the existence of the disorder. As a result of being diagnosed with a disorder that appears in *DSM-5*, the student can be entitled to special education-needs provision. It is often the case that if a link can be demonstrated between the disorder and detrimental learning outcomes, then a case can be made for qualifying for support.

## Overview of the book

Each of the following chapters includes a description of the learning difficulty (WHAT), followed by an inside look into the brain of a student with the disorder (WHERE), their unique working memory profile (WHY), and classroom strategies to support working memory (HOW). There are two types of strategies: **general working memory strategies** that can be applied to all students in your class, and **specific working memory strategies** for each learning difficulty. The final chapter (Chapter 9) provides the student with tools to empower them along their learning journey. The aim in supporting students with learning difficulties is not just to help them survive in the classroom, but to thrive as well. The strategies in the book can provide scaffolding and support that will unlock their working memory potential to boost learning. They are designed to be easily integrated within the classroom setting as a dimension of an inclusive curriculum and used in developing an individualized education program (IEP) for the student. The strategies recommended here can also complement existing programs that support a core deficit, such as a social skills program for a student with autistic spectrum disorder, or behavior modification for those with ADHD. Each chapter also includes:

- *Try It* box: Provides the reader with an opportunity to have a hands-on understanding of the material
- *Science Flash* box: Gives the reader a snapshot of current and interesting research related to each chapter
- *Current Debate* box: Discusses a controversial issue pertaining to the disorder

Working memory needs teachers like you. To have any impact, all the research published in hundreds of peer-reviewed articles, book chapters, and books over the past two decades needs teachers willing to take a

chance, to look out for students with working memory problems, and to support their needs. Working memory is a foundational cognitive skill, but it needs you to make the difference.

## Summary

1. Working memory is our ability to 'work' with information; think of it like your brain's *Post-it note.*
2. Working memory is a better predictor of academic success than IQ because it measures a student's **potential** to learn, not what they have already learned.
3. Working memory deficits are present in a range of learning disorders, from reading and math disabilities to developmental coordination disorder, ADHD, autistic spectrum disorder, and anxiety disorders.

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