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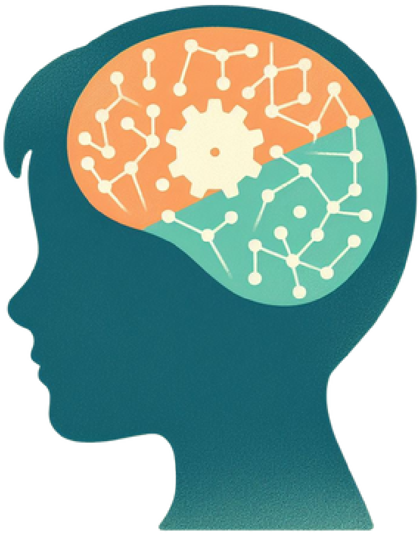
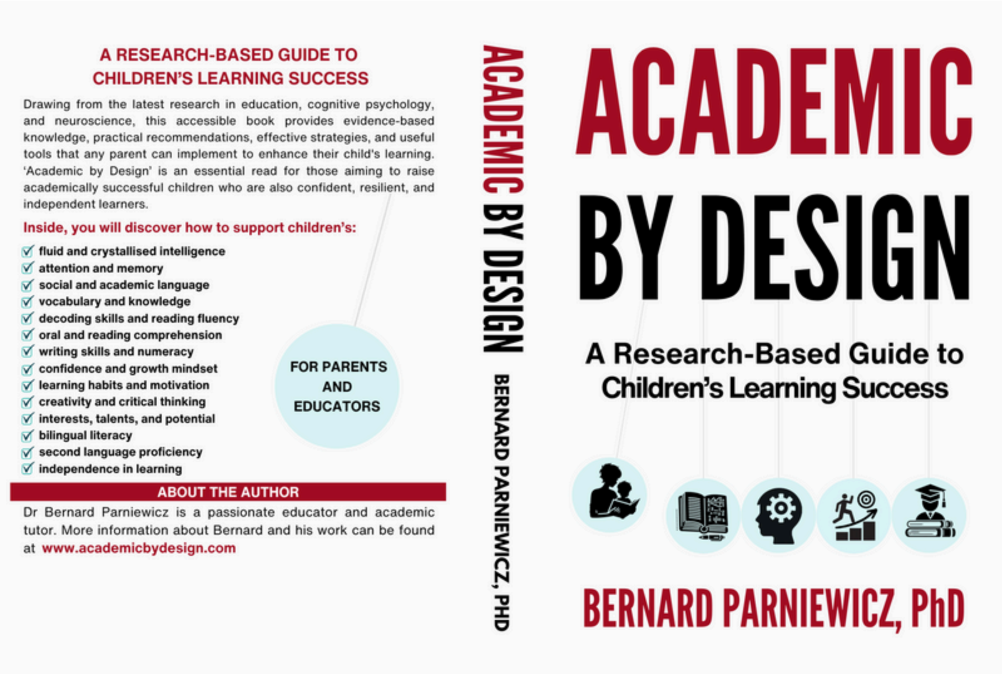


HOW TO SUPPORT CHILDREN'S WORKING MEMORY

BERNARD PARNIEWICZ, PHD

This booklet features a chapter from the book **'Academic by Design'.** The book is an essential read for those who aspire to raise **academically successful children** who are also **confident, resilient, and independent learners**. Spanning **607 pages** with **48 chapters** and enriched by **300 illustrations, charts, and tables**, this resource is the culmination of consulting over **1500 sources**. For more about the book, visit **www.academicbydesign.com.**



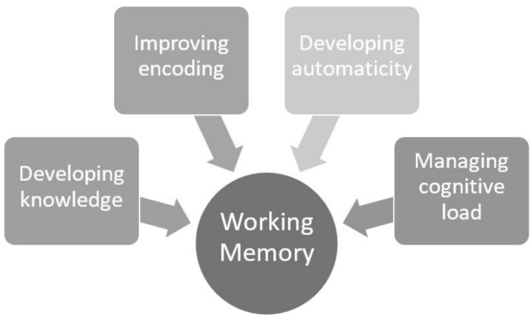
Chapter 13

Working Memory Cannot Be Improved but Can Be Supported

> 'The key to improved mental performance of almost any sort is the development of mental structures that make it possible to avoid the limitations of short-term memory and deal effectively with large amounts of information at once.'
>
> Anders Ericsson

As I said, working memory is always limited and forms, after attention, a second bottleneck in the learning process. Improving working memory is often perceived as the Holy Grail of education. If we could achieve it, we would make children learn faster and easier. Unfortunately, many experiments have shown that improving working memory can be challenging, if not impossible. Working memory is a highly heritable trait, and genetics play a significant role in determining its capacity. Despite claims that certain products, such as memory training and apps, can boost working memory, scientific studies have failed to provide strong evidence to support these assertions. The improvements achieved through these interventions have been underwhelming and often do not transfer to other learning contexts. For instance, the apps allegedly improving working memory via specifically designed mental games and tasks don't improve working memory in the context of learning language or mathematics. Similarly, activities such as chess, sudoku, and crosswords can be beneficial for mental stimulation, but they do not necessarily improve working memory.

Although it all sounds rather pessimistic, there are evidence-based strategies that can support this critical aspect of learning. One such approach is to prioritise a healthy lifestyle that includes a balanced diet, adequate sleep, and regular exercise. While these lifestyle factors may not directly enhance working memory capacity, they can create better conditions for optimal cognitive function. Since I don't have expertise in these aspects and many parents already provide their children with the right conditions for working memory to function, I will instead focus in this chapter on four promising instructional approaches that can support working memory and improve children's learning outcomes. These include: (1) improving automaticity, (2) developing knowledge, (3) improving encoding strategies, and (4) managing cognitive load. Let's delve into each of these in more detail.



Four ways to support working memory

DEVELOPING AUTOMATICITY

When I was learning to drive, I remember the first time I sat in the driver's seat. I was overwhelmed and intimidated by the number of things I had to remember and perform, such as turning the ignition, finding the brake, clutch, and accelerator pedals, knowing all the switches, changing gears, watching mirrors, the road, signs, and traffic, and listening to the driving instructor. Stress and anxiety made the entire experience even worse. At the beginning, I mixed up the pedals, forgot to check the blind spot, or turned on the windshield wipers instead of the indicator. Despite these initial scary experiences, I rather quickly became a competent driver (though my wife would strongly disagree). With time, all these individual processes became automated and merged into one behavior: driving. I did not have to think about using the pedals, indicators, and mirrors. Driving became like second nature to me and did not require conscious thought. I could listen to the news while driving, talk to a passenger, and admire the landscapes. Of course, my attention and working memory did not improve while learning to drive. Driving became easier as I developed automaticity (e.g., in changing gears) and gained knowledge and experience about what was happening on the road, which helped offload my limited working memory.

Automaticity is crucial for learning

The mechanisms responsible for automaticity are complex and still not very well understood. It seems that well-practiced skills become part of our procedural memory. Therefore these automated activities do not occupy so many slots in working memory and are more quickly and effortlessly retrieved from long-term memory. We could say that automaticity liberates us from the constraints of our limited working memory. It reduces cognitive load and allows more cognitive resources to be devoted to other tasks. Automaticity is a crucial element of effective learning performance (Anders Ericsson called it 'the hallmark of expertise'). Developing automaticity might be one of the most effective ways of supporting working memory. Some examples below.

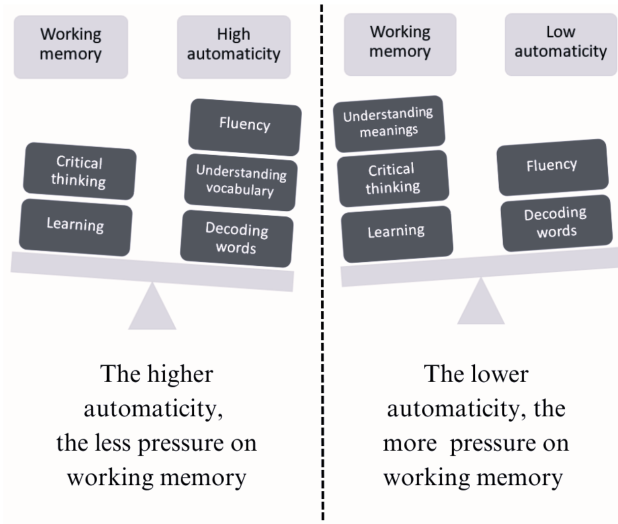
- Automaticity is essential for becoming proficient readers. Children first learn to recognise similar letters, such as 'p,' 'b,' or 'd,' and then progress quickly to recognising sight words (e.g., reading the word 'table' without focusing on letter-sound correspondence—they see the word and understand its meaning almost simultaneously). Children who have automated reading, becoming fluent readers, have more mental resources available in their working memory to understand word meanings and focus on text comprehension. Great readers who excel in comprehension have typically mastered automaticity. Their working memory isn't occupied with basic elements that learners with low automaticity struggle with.

- In basic math operations, such as addition and multiplication, automaticity allows students to efficiently solve more complex problems without consciously thinking through each step and without overloading their working memory capacity. For instance, consider the following calculation: 47 + 28. A person with automaticity in addition might instantly recognize that 7 + 8 equals 15, without needing to count or use a pen and paper. Then, they carry over the 1 from the sum (15) to add it to the tens column, recognizing that 4 + 2 (plus the carried-over 1) equals 7. Therefore, without pausing or breaking down the process, they quickly determine that 47 + 28 equals 75.

- In language learning, automaticity in grammar, pronunciation, and vocabulary enables learners to comprehend and produce language more rapidly and accurately.

- In music, automaticity in playing scales, chords, and rhythms permits musicians to focus on musical expression and interpretation rather than the mechanics of playing.

- Similar processes occur when children learn to ride a bike, type, swim, play games, and dance.



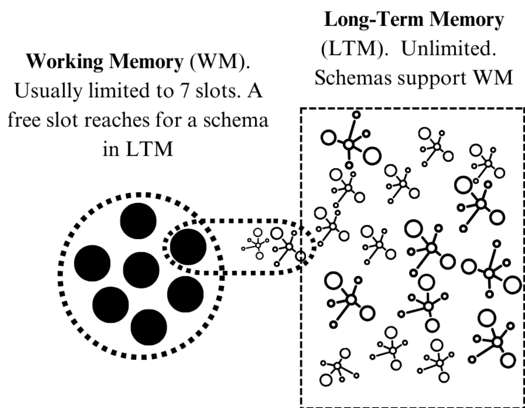
How is automaticity developed?

Automaticity is developed through practice, repetition, and overlearning. For example, children need to read extensively to automate reading. Similarly, to speak a second language fluently, they need to use it frequently. In a similar vein, children need to practice multiplication tables to become proficient in recalling results. Practice does not always make us perfect, but it helps us create stronger neural connections. At the same time, it is important to remember that not everything can be automated in learning. Automaticity seems to work well for relatively simple processes, such as recognising letters, reading, and simple calculations. While automaticity can greatly benefit cognitive functioning, higher-order thinking skills, such as critical thinking, cannot be automated since the level of processing is too demanding for automaticity to work. Thus, learners still need to engage in conscious thought and reasoning to perform complex tasks. Finally, the development of automaticity takes time, so patience is needed.

DEVELOPING KNOWLEDGE

Surprisingly, one effective way to enhance working memory is to focus on developing a child's long-term memory (knowledge). As previously discussed, working memory has a limited capacity of around seven pieces of information. However, the good news is that working memory can access information from long-term memory to support its processing.

Let's imagine that a child reads a sentence: 'The lion inhabits savannas'. This simple sentence can put a heavy load on the working memory of a child who does not know where lions live and what savannas are. However, a child having this knowledge in long-term memory can immediately form a mental picture of a savanna (a biome with sparse trees, grassy plains, warm climate, close to the equator, sunny, occasional droughts, migrating animals, occasional fires, etc.). Although this mental picture contains many interconnected details, working memory treats it as one entity occupying just one slot in working memory (it takes surprisingly little space for the amount of information it contains). This mental picture of a savanna supports and facilitates the child's understanding, offloads working memory, and lowers cognitive load. Such mental pictures in our minds are called schemas.



Long-term memory aids working memory by continuously supplying schemas that occupy minimal space within working memory.

A schema is a mental structure or framework in which we organise and categorise knowledge, information, and relationships. One can imagine a schema as a mind map of interconnected facts, information, related concepts, words, experiences, processes, or objects. Schemas are called the building blocks of knowledge for a reason. Well-developed and correct schemas speed up understanding and learning. That is why knowledge of the world (e.g. facts, processes, situations, objects) and knowledge of vocabulary improve reading comprehension and support thinking. Children who have more schemas in their long-term memory can quickly retrieve them to support their limited working memory.

Basic schema of a dog:
four legs, tail that wags, not a cat, friendly, barks, furry, playful, cute, bones

Advanced schema of a dog:
breed, pedigree, salivate, handler, domestic, feral, faithful, kennel, domestication, mongrel, feral

Schemas are crucial for a child's development because they assist children in organising and comprehending the world around them. Children with a well-developed schema of a dog can more effortlessly categorise and classify new information about dogs, facilitating more efficient learning.

How does knowledge support experts?

Most people believe that chess masters possess exceptional, almost inhuman memory that allows them to play so strategically. However, this is not entirely true. In a famous experiment conducted by Dutch psychologist Adrian de Groot, chess masters and novice players were asked to look for a few seconds at a chess position with 25 pieces. The position was a snapshot of an actual game. Then players had to recreate the position on a chessboard from memory. For the grandmasters, this was not a problem, but predictably, it was challenging for the beginners. Then, de Groot did something surprising; he placed the 25 pieces randomly, which was highly unlikely in a real game. Both the chess masters and novices had enormous problems with placing the pieces in the correct places. So what exactly happened here? In the first scenario, chess masters employed the knowledge stored in their long-term memory to recreate the position of the pieces. Since the position was a snapshot of an actual game, most of them were familiar with similar scenarios. However, randomly positioning the pieces on the chessboard caught them off guard. They had nothing in long-term memory to confidently support their working memory. Generally, chess masters don't differ much from novices concerning their working memory. Still, vast differences exist between them in knowledge and experience.

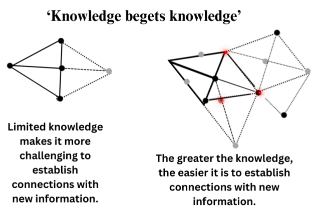
Player level	Number of pieces correctly placed	
	Mid-game	*Random*
Novice	5	2
Expert	16	3

Mid-game: experts recall more pieces than novices.
Random: the number of pieces correctly recalled does not differ between experts and novices.
Conclusion: Expert chess players rely on pattern recognition and mental representations of chess positions, rather than just brute force calculation, to make quick and accurate moves.

The importance of developing children's knowledge for learning and reading cannot be overstated.

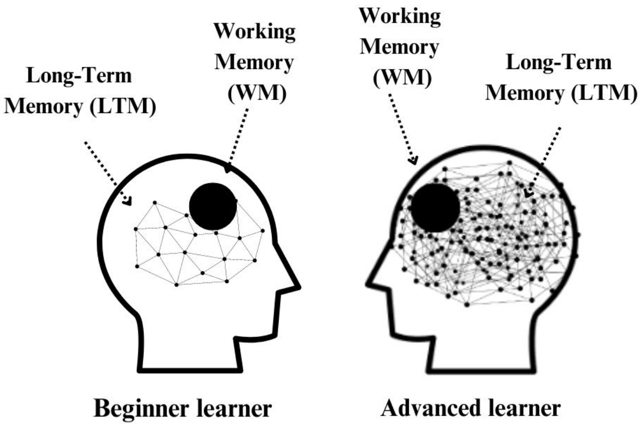
- Knowledge stored in long-term memory helps in the efficient formation of connections between new and previously acquired information. Knowledge-rich children acquire new knowledge faster. The more children know the more working memory they have left to process and encode and transfer new information from working memory to long-term memory. Children who have more knowledge can more effectively create associations and mnemonics.

- When we have prior knowledge related to a new topic or concept, it is easier for us to understand and remember new information related to it. This is because our existing knowledge serves as a scaffold for new information, making it easier to organize, categorize, and retain. Children with better developed knowledge focus more easily on related information. They also have more working memory for more complex tasks (e.g. critical thinking and creativity).



Some learners often have a wider range of prior knowledge and experiences, which allows them to make connections and build upon existing knowledge more easily.

Therefore, building a strong foundation of knowledge and skills through practice and repetition is an effective way to support working memory. Parents who build a strong foundation of children's knowledge can enhance their ability to learn new information. That is why I will revisit knowledge development later in this book (see Chapter 28).



Beginner learners and advanced learners differ mainly in the number and quality of connections in long-term memory (LTM). Consequently, beginner learners cannot rely on LTM and need to rely more on their limited working memory (WM).

IMPROVING ENCODING

Effective learning necessitates the successful transfer of information from working memory to long-term memory. As previously described, the transfer of new information to long-term memory becomes smoother when children possess automated reading skills and well-developed knowledge, both of which are prerequisites for strong comprehension skills and effective learning. In this manner, there is less strain on working memory, enabling new knowledge to more seamlessly integrate with previously acquired information. Another crucial element that bolsters working memory is the effective encoding of information.

Let's consider a scenario where a child encounters the word 'rectitude' in a text and learns that it means 'morally correct behavior or thinking'. Now, the child faces the task of transferring the word label (rectitude) and its meaning to long-term memory. This process isn't straightforward. A common approach is repetitive recitation, hoping the word will stick through the sheer force of repetition. A more effective learning strategy involves connecting the new word to something the child already knows. For instance, if the child is familiar with the word 'attitude', she might grasp the word 'rectitude' more quickly and firmly. Another method could involve creating a mnemonic: 'rectitude' = 'corRECT' and 'atTITUDE'. This example illustrates effective encoding. Children should be taught various methods to establish associations, relationships, and connections between new information and the knowledge already stored in their long-term memory. This process also highlights how knowledge bolsters working memory; children with a richer vocabulary grasp unfamiliar words more rapidly.

Surface vs. deep learning

Transfer of information from working memory to long-term memory is not accidental and often requires deep engagement and mental effort. Daniel T. Willingham famously remarked that 'memory is the residue of thought'. Students are required not only to pay attention to the material they are reading or learning but also to actively think about it. The more a child engages in thinking about the material or skill they're learning, the better the learning outcomes. Consequently, a distinction can be drawn between shallow or surface learning, which involves minimal mental processing of information, and deep learning, characterised by extensive processing that occurs within our working memory.

Both deep and surface learning approaches come with distinct advantages and limitations.

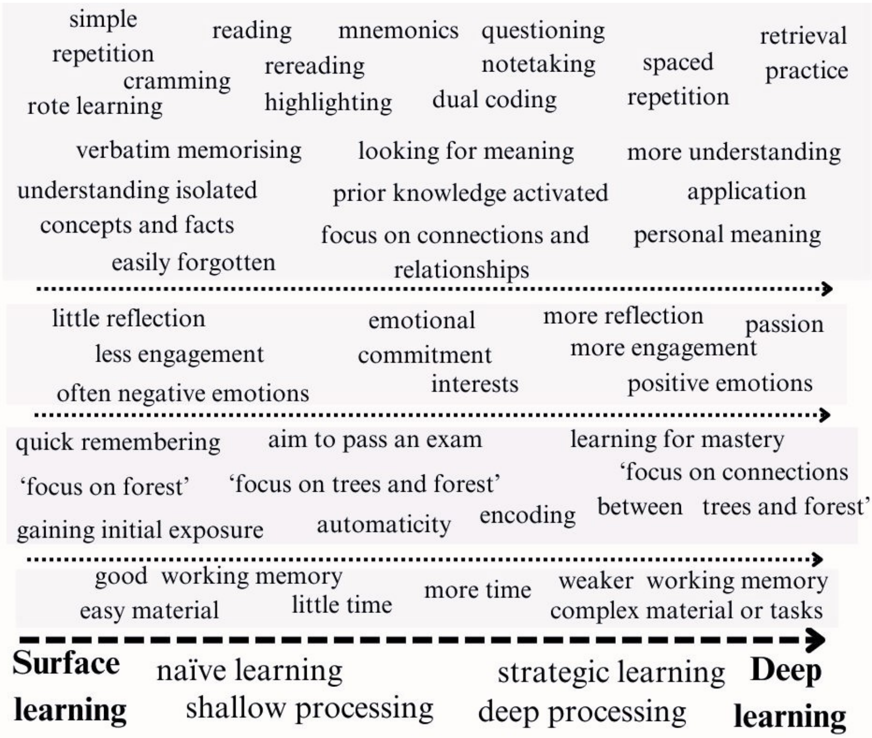
- Deep learning involves a comprehensive understanding and active engagement with the material which is better for the retention of information in long-term memory. When students grasp underlying principles, they become better critical thinkers—they can analyse, evaluate, and apply knowledge effectively to solve complex problems. This depth of understanding also grants students greater flexibility and adaptability in applying fundamental concepts across various contexts. Deep understanding often leads to heightened interest and motivation in the subject, making it more engaging and enjoyable as students comprehend the 'why' and 'how' behind the information. Furthermore, deep learning incorporates effective strategies like mnemonic devices, segmentation of material for easier comprehension, retrieval practice, spaced repetition, dual coding (utilizing visual and auditory channels), and verbalising information for enhanced retention. Consequently, deep learning is particularly beneficial for learners with weaker attention and working memory, aiding in processing and retaining information effectively. Finally, deep learning facilitates learning complex material and supports cognitively heavy activities e.g. critical reading and writing. On the other hand, surface (shallow) learning primarily focuses on memorisation and rote learning, lacking a deeper understanding of underlying concepts. It's often criticised as a repetitive, thoughtless process akin to cramming and drilling.

- Despite this, there are contexts where surface learning proves beneficial. For instance, in the introductory stages, surface learning facilitates familiarity with basic concepts and terminology, especially in complex or entirely new subjects. There are instances where students benefit from absorbing information without necessarily exploring its intricacies, such as when learning the alphabet, multiplication tables, poetry excerpts, foreign language vocabulary, or developing reading fluency. Surface learning provides opportunities for repetition of fundamental elements, essential for embedding them firmly in our minds and developing automaticity.

- For instance, when an English as a Foreign Language (EFL) student listens to English songs, they may not understand all vocabulary and grammar, but they develop familiarity with the language, pronunciation, intonation, idiomatic language, and accent.

- Also, in time-constrained situations such as in last-minute test preparation or when quick overviews are needed, surface learning might be more practical. It can also be suitable for students who need basic familiarity with a subject without requiring an in-depth understanding. Surface learning can serve as a foundational layer upon which deeper understanding can be developed. Finally, it may suit certain learners with a more retentive memory due to better attention, working memory, and accumulated knowledge. To sum up, surface learning isn't inherently negative and can be necessary in specific contexts.

- At the same time, it's essential to acknowledge that surface learning, while sometimes necessary, lacks comprehension and may hinder the transfer of knowledge in complex scenarios, restricting critical thinking, and causing monotony. Therefore, a balanced approach that combines both types of learning—often initiating with surface learning and progressing towards deeper understanding—typically yields superior long-term learning outcomes. Both types contribute uniquely to knowledge acquisition and should complement each other for more effective learning experiences.



Surface learning - Deep learning Continuum

Shallow processing vs. deep processing

Shallow processing and deep processing are terms often linked to the concepts of surface and deep learning. Shallow processing refers to a superficial way of engaging with information. It involves minimal mental processing, like focusing on the surface-level characteristics of information. This type of processing often leads to surface learning, where learners memorise information temporarily without deeply understanding or connecting it to existing knowledge. Deep processing, on the other hand, involves a more profound engagement with information. It entails actively thinking about the material, making connections with prior knowledge, and critically analysing the content. This approach typically leads to deeper learning, where information is thoroughly understood and retained in long-term memory.

- An example of non-existent processing: A child reads a book but thinks about something else entirely. Consequently, these children cannot recall the book's content as their minds were distracted, focusing on something different. In this scenario, the information from the book is not processed.

- An example of shallow processing: A student reads the text without delving deeper into its meaning or context. They skim through the material without engaging in thoughtful analysis. Shallow processing might suffice to pass a test but often falls short in fully understanding the subject or topic, leading to inadequate long-term retention of information.

- An example of intermediate processing: A student reads the text, reflects on their understanding, silently formulates questions, and relates the content to their personal experiences. They revisit the text, highlighting crucial sections. However, they may not actively monitor their comprehension, overlooking reasons behind their difficulties in understanding certain sentences. Their focus might be on memorisation rather than comprehension and strategic learning of essential information.

- An example of deep processing: A student reads the text while actively seeking out critical vocabulary and concepts. They ensure a comprehensive understanding of essential terminology and underlying contexts. The student adopts effective note-taking strategies by paraphrasing information and integrating personal insights. They further organise these notes by categorising them or creating mind maps, facilitating connections and understanding the relationships between various concepts and ideas. This approach helps them view the material holistically, breaking it down into manageable segments for better comprehension. The student devises question-and-answer flashcards to aid in subsequent revision and regularly reviews their notes through distributed or retrieval practice. Additionally, they engage in self-questioning and take the initiative to explain the material to a peer or friend, reinforcing their own understanding.

Cognitive processing while reading	
Shallow processing	A student reads texts without deeper thinking and engagement. They do not delve deeper into the underlying meaning and context. They skim through the text quickly without fully comprehending the main ideas or details. They re-read the text and highlight important fragments. However, they don't monitor their comprehension (e.g. why they do not understand certain sentences) and don't use effective note-taking techniques. They attempt to memorise everything or isolated details rather than understand the context first and then strategically learn the most important information.
Deep processing	A student reads the text and looks up critical vocabulary and concepts. They make sure they understand key vocabulary, underlying context, take good notes (summarise and paraphrase the main ideas in their own words), reflect and create question and answer flashcards for subsequent repetition. They review their notes using retrieval practice. They self-question. They make connections between the text and prior knowledge or personal experiences to gain insights and relate to the material. They also explain the material to friends.

	Cognitive processing while listening to a teacher
Shallow processing	A student listens to the teacher and pays some attention but their minds tend to wander a bit. They check their phones. They focus solely on note-taking without actively processing or reflecting on the concepts being presented. They note down verbatim what the teacher says or they borrow notes from a friend to learn from them. They re-read the notes before the exam. They rely on memorisation or rote learning without grasping the underlying concepts.
Deep processing	A student listens attentively and critically, paraphrases the teacher's lecture, makes summaries, generates questions, uses concept maps and mind maps to organise and understand the relationships and information visually in a hierarchical way. They make connections to prior knowledge, and reflect on the material's implications and applications. They minimise distractions and maintain focused attention. They ask questions during or after the lecture to clarify confusing points and deepen comprehension. They organise comprehensive notes and transform them into flashcards. They make connections between the lecture content and prior knowledge/experiences to enhance understanding and retention and make it more meaningful.

	Cognitive processing while writing a non-fiction project
Shallow processing	A student starts writing the project without preparation. They write about what they already know. Alternatively, they copy information directly from sources without fully understanding the content. They rely heavily on quotes and paraphrasing without critically analysing the information. They use generic or overused phrases and sentences without adding original insights. They focus mainly on meeting the word count or length requirements without delving into the topic's depth.
Deep processing	A student makes plans and conducts extensive research from multiple reputable sources to capture diverse perspectives on the topic. They read these materials critically and create notes in which they describe, explain, summarise, paraphrase and comment on the collected information. They ask themselves questions such as: 'Why am I taking this note?', 'Why is it important?', 'How does concept A relate to concept B?'. They use outlines and outlining software to organise the information. They analyse and synthesise information to form cohesive arguments and develop a well-structured and coherent narrative. They also incorporate their own insights and analysis into their writing and use evidence to support their claims acknowledging any biases or limitations in the information presented.

Cognitive processing while reading aloud	
Shallow processing	A parent reads a book aloud. The child listens passively as the parent reads the text without explaining the meaning or context behind the story. The parent rushes through the book, not allowing the child to ask questions or reflect on the vocabulary, facts, and concepts presented. There's no effort made to stop and explain or discuss unfamiliar words with the child. Furthermore, the parent reads aloud without putting much emphasis on tone, expression, or emotion, making the reading experience less engaging for the child. They only identify and state the names of characters, objects, or events without delving into further discussion or exploration.
Deep processing	A parent carefully chooses an interesting and comprehensible book to read aloud to the child. During the reading, the parent ensures engagement and fun, discussing the book with the child and asking open-ended questions about the characters, plot, or themes to stimulate the child's thinking and analytical skills. The parent targets and explains important vocabulary and concepts, helping the child grasp their meaning and relevance. To make the story more relatable, the parent encourages the child to draw connections between the events in the book and their own experiences. When they encounter unfamiliar words, the parent pauses to discuss them with the child. To aid in understanding new words, the parent provides context clues or uses illustrations from the book to help the child infer their meaning within the text. The parent motivates the child to use the new words in their own sentences or stories, reinforcing their understanding and application. To ensure lasting comprehension, the parent revisits previously encountered words and concepts during subsequent readings, reinforcing the child's learning over time. Lastly, the parent explores the moral or lesson that can be learnt from the story and discusses its implications, encouraging the child to reflect on the deeper messages conveyed by the book.

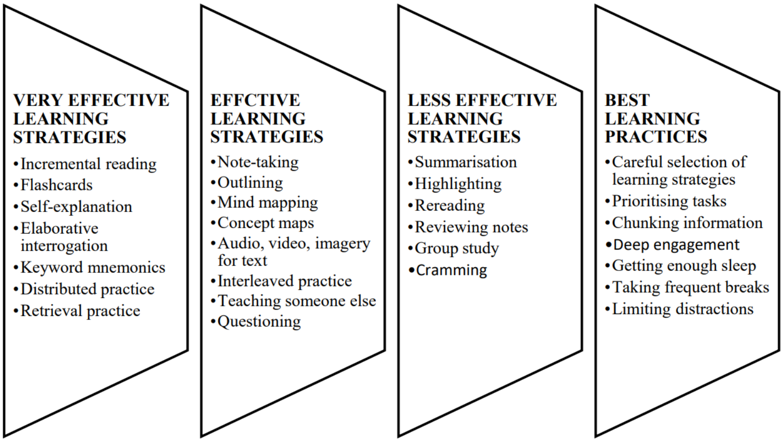
Cognitive processing while explaining a new word to a child	
Shallow processing	A parent tells a child what a novel word means, for example, 'hostile means unfriendly'. They offer a simple dictionary definition of the word without providing any additional context or examples. They briefly explain the word's meaning without engaging the child in further discussion or exploration.
Deep processing	A parent defines the novel word and asks the child to say the word 'hostile' aloud. They provide examples of using the word in sentences to illustrate its meaning and usage in different contexts. They then ask the child to explain the novel word in their own words. Additionally, they connect the word with the child's life, asking questions like 'Has anybody ever been hostile to you at school?' and 'What happened?'. They also explore scenarios like 'If I were hostile to you, what would you do?'. This approach aims to make the word's meaning relevant and relatable to the child's experiences. The parent encourages the child to actively use the word in sentences or conversations, which reinforces understanding and retention. The parent fosters curiosity by encouraging the child to ask questions about the word's meaning and to discuss its potential implications and uses. To reinforce vocabulary learning, the parent revisits the word in subsequent discussions, highlighting its relevance in different contexts. Finally, the parent ensures that the whole experience is enjoyable. By making vocabulary learning an exciting and interactive activity, the child is more likely to stay motivated and enthusiastic about expanding their language skills.

Cognitive processing while learning vocabulary	
Shallow processing	A student finds an unknown word in the text, but ignores it and continues to read without attempting to figure out its meaning ('if it is important, I will see it again'). Alternatively, they guess the word's meaning based on the context without considering additional sources for clarification.
Deep processing	A student finds/hears a new word, makes a mental note of it, or writes it down to look it up. They connect the unfamiliar word to known words or roots to make an educated guess about its meaning. They ask for the word's meaning. They add the word to their list of important vocabulary, create a mnemonic for the word, build a personal connection, say it aloud, self-test on the word a few days later, use it in sentences, employ emotions and visualisation to remember the word, use good apps for learning vocabulary. They consult a dictionary to find the word's definition, but also examine its etymology and usage in different contexts. They reflect on the unfamiliar word. They take a conscious effort to incorporate the new word into one's vocabulary to reinforce understanding.

Encoding strategies

Several science-based methods improve encoding information. Good examples are generative learning approaches such as summarising, mapping, drawing, self-testing, self-explaining, teaching others, spaced repetition/distributed practice, retrieval practice, keyword mnemonics, and outlining. These methods differ in effectiveness and are used for different purposes (e.g. outlining works great in writing, keyword mnemonics in language learning). Often, they can be used together (reading, outlining, and notetaking). Many of these methods are unknown to students (and parents). Consequently, students often use less effective learning methods; e.g. rereading texts, highlighting, reviewing notes, or cramming before exams.

These generative strategies are particularly important when students want to truly understand a certain topic (have a more coherent and understandable representation of the material), want to remember the material longer, and are interested in mastery learning. Generative strategies are incredibly important for students with poor working memory. They make memorisation and learning more effective than shallow interaction with the text/materials/task.



When choosing the most suitable strategy, it's important to consider factors beyond just effectiveness. This includes the specific learning environment, the age and skills of the learners, their preferences and goals, the time they have available for learning, their prior knowledge, motivation, resources, adaptability, and autonomy.

Some important caveats

- The obvious problem is that deep processing can be strenuous, even for older students. It is hard to require that depth of processing from young children for a prolonged time. Increasing children's engagement in learning is one of the best ways to increase their depth of processing. Children who are interested or passionate about a subject or a topic usually pay more attention, and invest more time, energy, and effort in learning. Also, children who are offered a choice, and are provided with a supportive environment in which they can ask questions, be successful, fail without negative consequences, and, last but not least, have fun also tend to increase their depth of processing.

- Generally, encoding strategies work much better for students and adults than for primary-age children. At the early stages of life, developing automaticity and knowledge is the priority and helps students take advantage of many encoding strategies later. Still, parents and teachers should develop children's awareness of effective methods and good learning habits early. Students who learn about these methods later often cannot change their learning habits and stick to less effective methods.

- Only a few students utilise the strategies that are described here. Unfortunately, schools do not teach students how to learn effectively, and most students prefer to use intuitive but ineffective strategies. While the lack of effective learning strategies may not significantly affect children's learning in their early years of schooling, it becomes essential in secondary school, university, and the workplace when the role of unsupervised learning increases. This is particularly important for students with poor working memory. Therefore, students need to be trained to use effective learning techniques and must practice them to make them work. It does not come naturally; rather, it needs to be taught explicitly. Even elementary school children can and should be introduced to how their brain works and how to learn effectively. Later, this topic should be revisited to enhance student knowledge gradually.

- Students who have more knowledge stored in long-term memory find it easier to connect new information with existing information. Training on improving children's ability to encode information is not likely to work without a foundation of well-developed knowledge. And herein lies the greatest challenge (hence Chapter 28 on developing knowledge).

Encoding techniques
Incremental reading is a learning and reading technique that was popularised by Piotr Wozniak, the creator of the SuperMemo software. It is a method designed to help advanced learners efficiently absorb and retain large amounts of information over time. The main idea behind incremental reading is to break down large pieces of information, such as articles or textbooks, into smaller, manageable chunks. These chunks could be paragraphs, individual sentences, or even smaller snippets of text. Learners then read and process these chunks in a spaced repetition manner. In short, incremental reading combines reading, comprehension, creating Q&A flashcards, summarisation, self-explanations, practice testing, and distributed practice. **Effectiveness: very high.**
Practice testing (retrieval practice) is a learning strategy that involves actively retrieving information from memory through self-quizzing or testing. It is a highly effective and evidence-based technique to enhance long-term retention and improve learning outcomes. Instead of passively reviewing study materials, low stake practice testing requires actively engaging with the material by trying to recall information. **Effectiveness: high.**
Distributed practice, also known as **spaced practice** or **spaced repetition**, is a learning strategy that involves spreading out study sessions over time instead of cramming all the study material in a single session. It is a highly effective technique for improving long-term memory retention and enhancing learning outcomes. In distributed practice, learners engage with the study material multiple times, with each study session spaced out over several intervals. The key principle is to allow time between study sessions to facilitate memory consolidation and retrieval. **Effectiveness: high.**
The self-explanation technique is a learning strategy in which learners actively explain the material they are studying to themselves. It involves articulating the steps, thought processes, and reasoning behind how they understand and solve problems or concepts. By explaining the information in their own words, learners deepen their understanding and facilitate better retention and transfer of knowledge. **Effectiveness: high.**

Encoding technique
Elaborative interrogation is a learning strategy that involves asking a child 'why' questions. When using this technique, learners go beyond simply memorising facts and engage in a deeper level of cognitive processing. They actively generate explanations and create meaningful associations between new knowledge and their existing mental frameworks, which enhances understanding and long-term retention. **Effectiveness: high.**
Note-taking is a learning strategy that involves capturing and recording important information from lectures, textbooks, presentations, and educational materials. Effective note-taking helps learners organise and summarise key points, aiding in comprehension, retention, and later review of the material. There are several good note-taking methods (e.g., Cornell Method and Outline Method). I often recommend to older students the Zettelkasten method originally developed by German sociologist Niklas Luhmann. It is a sophisticated and powerful method used to manage and connect ideas, allowing for creative thinking, knowledge synthesis, and research development. While the original Zettelkasten method was based on physical index cards, modern versions can be implemented using digital note-taking software (e.g., OneNote, Evernote) or platforms that support linking and organization of notes (e.g., Notion). **Effectiveness: low to high** (depends on the technique and the task).
Interleaved practice is a learning technique where different topics or skills are mixed together during study or practice sessions, rather than focusing on a single topic at a time. In other words, instead of 'blocking' study sessions by spending an extended period on one subject before moving to the next, interleaved practice involves alternating between different subjects or skills within the same session. During interleaved practice, the student might alternate between maths and history topics within the same study session, spending shorter intervals on each subject. The key idea behind interleaved practice is to challenge learners to recall and apply their knowledge in a more varied and unpredictable manner. When topics are blocked, learners may experience the illusion of competence, feeling like they have mastered a topic after continuous practice. Interleaved practice helps learners identify areas of weakness or gaps in their understanding. **Effectiveness: medium.**
Keyword mnemonics is a memory aid strategy used to improve the recall of information by associating new concepts with familiar and easily remembered keywords or mental images. When learning new information, learners identify key or critical words that represent the main ideas or concepts. These keywords should be the focus of the mnemonic. Then they associate each keyword with a similar-sounding word or image that is already well-known or familiar. This association acts as a memory link between the new information and something that is easier to remember. Keyword mnemonics are particularly useful when trying to remember foreign language vocabulary, technical terms, or any information that can be challenging to memorise directly. **Effectiveness: medium.**

Encoding techniques
Summarization technique is a learning strategy that involves condensing and rephrasing a large amount of information into a concise and coherent summary. The goal of summarization is to capture the main points, key ideas, and essential details of a text or a lecture while omitting unnecessary or less relevant information. **Effectiveness: low.**
The highlighting technique is a common method of studying, where learners use coloured highlighters to mark or underline key points, important information, or significant details in a text, such as textbooks, articles, or lecture notes. While highlighting can be helpful, it is more effective when combined with other study techniques like note-taking, summarization, and active retrieval practice. Highlighting alone does not guarantee deep comprehension. Highlighting should be a supplementary aid, not a replacement for active learning strategies. **Effectiveness: low.**
Rereading or reviewing notes is a common and straightforward study technique where learners go over their previously taken notes to reinforce their memory and understanding of the material. While rereading and reviewing notes can be beneficial for memory retention, it is essential to complement this method with other active learning strategies. Strategies like retrieval practice (e.g., self-quizzing) and spaced repetition can further enhance learning outcomes and comprehension. **Effectiveness: low.**
The cramming method refers to an intense and concentrated study approach where learners attempt to absorb a large amount of information in a short period, usually right before an exam or assessment. It involves trying to learn and memorise a significant amount of material in a brief amount of time, often sacrificing sleep and breaks to maximise study time. While cramming can sometimes result in short-term gains in knowledge and performance, it is generally considered an ineffective and inefficient study strategy for several reasons. When information is crammed into memory in a short time, it is more likely to be forgotten quickly after the exam. Cramming often focuses on rote memorisation without a deep understanding of the material. This can lead to difficulties in applying the knowledge to real-life situations or higher-level problem-solving. The pressure and stress of cramming can negatively impact learners' well-being and exam performance. It can lead to feelings of anxiety and decrease the ability to recall information accurately during the exam. Cramming does not allow for spaced repetition, which is a well-established technique for promoting long-term retention and memory recall. **Effectiveness: very low.**

MANAGING COGNITIVE LOAD

Let's consider two people owning different cars—one drives a BMW with a powerful engine, while the other drives a Mini Cooper equipped with a smaller engine. Despite the differences in their vehicles, both individuals can reach their destinations. However, the Mini Cooper owner must acknowledge that their journey may take longer. They need to operate within the limitations of their car's engine, such as driving at a slower speed, taking frequent breaks, and avoiding steep terrain. Ignoring these limitations may cause the smaller engine to fail, leading to no progress. On the other hand, the BMW owner can reach their destination more swiftly. Yet, this assumes they don't encounter any accidents or lose interest in reaching their destination.

A similar principle applies to children and their working memory. Children with poor working memory can learn anything they want, but it might require more time. It's crucial not to overburden or push their working memory beyond its limits, as doing so can cause it to stall. In psychology, this stalling of working memory is known as cognitive overload, a concept pioneered by psychologist John Sweller in his influential Cognitive Load Theory. Some experts, like Professor Dylan Wiliam, emphasise that cognitive load theory is among the most crucial aspects for educators to understand. It's challenging to disagree with that assertion, as effective learning heavily relies on managing cognitive load.

All of us must have experienced a situation in which our working memory was completely overwhelmed. It happens when we read a text with plenty of challenging vocabulary and concepts about a topic we know little about. Or when we try to speak a foreign language we are not proficient in. The task of understanding a native interlocutor, producing meaningful sentences, and sustaining a conversation is extremely taxing. Cognitive overload also happens when a teacher (or parent) ignores the inherent limits of working memory and inundates a child with too much information and knowledge (or provides information in a confusing way). The same happens to a child trying to read a challenging text without well-developed automaticity. Even children with relatively good working memory experience cognitive overload when faced with more challenging tasks, e.g. dividing 2590 by 74 (answer 35). Cognitive overload affects people when they learn to ride a bike, dance, or drive and have to perform many activities simultaneously. Multitasking, stress, anxiety, high-stakes exams, and limited time for learning can all make learning even more challenging. It puts a lot of additional pressure on working memory. When a student experiences cognitive overload, working memory has too much information to process (it has bitten off more than it can chew). The learner becomes overwhelmed and learning stalls. In moments like that, students often switch off, lose motivation, get frustrated, and stop enjoying the learning process.

The human brain is not a computer but similarities exist

I often liken the challenges children/students face with working memory and cognitive overload to an issue I encountered with my old PC 25 years ago. My PC had very limited RAM (computer working memory), and upgrading it wasn't possible. However, it boasted pretty solid storage (computer long-term memory). During a crucial project, I couldn't run the applications my colleagues used on their more powerful computers, since my PC faced its version of cognitive overload. Though it seemed rather unfair, I had no choice but to adapt. Rather than giving up, I overhauled my entire workflow. I restricted my browser to a single window and focused solely on essential tasks, eliminating unnecessary graphics. Opting for smaller, efficient applications, I avoided multitasking at all costs. I crafted a flawless workflow around my imperfect hardware. Despite limitations, I completed a better project than my colleagues working on superior machines. I simply used my PC more efficiently or effectively than they did. This experience taught me the value of achieving more with less by adopting smarter and more efficient work strategies.

Learning task	How cognitive overload might affect the task
Reading	A child who uses up all their working memory on decoding (sounding words out) does not have any free slots in memory for understanding what they have just read. A child who struggles with understanding of a text does not have the resources to think critically about the text. High cognitive load leads to slower reading, difficulty in retaining information, and a higher chance of misinterpreting content.
Speaking in a foreign language	A student who focuses on understanding what another person has said does not have sufficient free mental resources to formulate an answer and respond appropriately during a conversation. A student who struggles to retrieve vocabulary, grammar rules and pronunciation does not have any free resources to communicate effectively. This may result in slower speech, more errors, and difficulties in expressing thoughts accurately.
Presentation in a native language	A child who is stressed and thinks about what their friends might say about their presentation, start having problems with their delivery. This may lead to nervousness, forgetfulness, or stumbling over words.
Writing an essay	Writing involves multiple cognitive processes, including generating ideas, structuring content, and ensuring proper grammar and spelling. High cognitive load can make it challenging for students to manage all these aspects effectively, potentially leading to lower-quality essays.
Learning for a test from a challenging text	A child who does not understand a text very well does not have the free resources to encode information to long-term memory. A child who tries to memorise too much information, experiences cognitive overload and difficulty to retain key concepts.
Classroom task	A child who needs to follow complicated instructions that contain multiple steps does not remember these steps. Also, they cannot focus on the task, affecting its outcome.
Mental arithmetic	A child who needs to add 14, 19 and 44 in their head, focuses on adding 14+ 19 and arrives at 33 but does not have the resources to remember 33 to add to it 44 and get the result.

What are the implications for parents and children?

- Unnecessary cognitive load should be avoided or reduced. It is important for children with weaker working memory. Parents/teachers who try to teach children too much and/or too quickly are likely to be unsuccessful. It is like pouring water (knowledge) too quickly into an enormous bottle (the child's mind) with a small neck (the child's working memory). A spill (cognitive overload) is unavoidable. Cognitive overload does not only stall learning, it also causes frustration, anxiety, and lowers learning motivation. Also, students themselves need to learn how to regulate their cognitive load.

- Children who are poor or average readers experience cognitive overload more often than children who are proficient readers. Poor readers have less automaticity and knowledge. They understand less. Therefore, developing a high level of reading comprehension skills is crucial for supporting children's learning and academic performance.

- There are many other strategies to lower cognitive load: e.g., chunking (described in detail below), prioritising (see the Pareto Principle below), appropriate sequencing of information, worked examples (also see below), comprehensible input, using well-deigned multimedia, adding subtitles when learning a foreign language, using a pop-up dictionary to look-up unknown words, explaining difficult words using easier words, complementing text with diagrams or images, using child's first language to teach a second language (reading bilingual books, teaching cognates, watching a movie in a first and than a second language), asking a student to read a text at home before discussing it at school, using technology to lower cognitive load, using stories, using text with audio (to use auditory and visual channels in working memory), turning off distracting music/TV, using YouTube captions in the child's first/second language, repeated reading, increasing difficulty, spiral curriculum, using graphics, graphic organisers, and preteaching.

Worked example

Solve the following equation: 2x + 5 = 15

Step 1: Subtract 5 from both sides of the equation

$$2x + 5 - 5 = 15 - 5$$

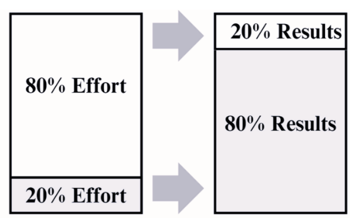
$$2x = 10$$

Step 2: Divide both sides of the equation by 2

$$(2x)/2 = 10/2$$

$$x = 5$$

Worked examples are problems that have been solved and explained clearly step-by-step.

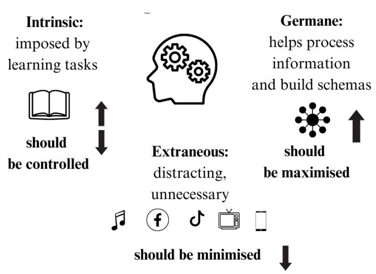


The Pareto Principle suggests that approximately 80% of the results come from 20% of the efforts. Although this rule might not apply in schools where everything seems to matter, it often works in more informal learning. Simply, learners should be able to identify the key information that is likely to contribute the most to their understanding and performance.

- Chunking is a cognitive process essential for effective learning, involving the breakdown of information into smaller, well-organised, and manageable units, or 'chunks'. Let me give an example. Although we are unlikely to remember the string of letters: VTICBSNPESCNNCBB, we will have no problems with it when the letters are grouped in a meaningful way, e.g., ITV, CBS, ESP, BBC, CNN. What was an impossible task due to the limitation of working memory becomes an easy task since these five chunks are within the limits of working memory and are supported by our knowledge stored in long-term memory (we know what BBC, CNN, and ITV mean). These chunks are easier to process and retain, since they support learning by managing working memory limitations, reducing cognitive load, and enhancing comprehension. Although few people are familiar with the chunking technique, we all use it subconsciously at least at times since this approach naturally aligns with how our brains encode information. For instance, in everyday tasks like shopping, we instinctively chunk items into food categories (e.g., vegetables, sweets, fruits, dairy, drinks). When we try to remember a long string of random numbers like '739216825'; we chunk it into smaller groups like '739-216-825' since it is easier to remember. We use the principle of chunking in lists, bullet points, infographics, or tables we use to present information. In academic contexts, chunking proves invaluable. When memorising a long passage, breaking it into smaller phrases or sentences and rehearsing each chunk separately can make it easier to remember the entire passage later. In mathematics, complex problems can be broken down into smaller, manageable steps, aiding students in problem-solving. Similarly, in language learning, chunking can assist in vocabulary acquisition, grammar comprehension, and sentence structure understanding. For example, learners studying verb conjugations in Spanish can chunk regular verbs based on recognisable patterns in their endings: -ar Verbs: hablar (to speak), bailar (to dance); -er Verbs: comer (to eat), beber (to drink); -ir Verbs: vivir (to live), abrir (to open). This method is particularly beneficial for tackling complex or unfamiliar material, allowing learners to approach it one manageable piece at a time, gradually building mastery. Experts in various fields, such as chess players or proficient readers, exemplify the efficacy of chunking in skill development. For instance, when we learn to read, we need to learn first to recognise the shapes of letters, then associate letters with sounds, learn to read sight words and some longer words, and master vocabulary, lexical chunks, grammar, and syntax to support quick reading and comprehension. There are two clear implications ensuing from this short section. Firstly, to effectively integrate chunking into children's learning, parents or educators need to identify foundational concepts and basic schemas of knowledge. For instance, when teaching children to read, it's more manageable to begin with teaching letters rather than whole words. Subsequently, patterns, categories, and relationships should be established, e.g., by grouping similar items and recognising meaningful connections (this can be exemplified by the use of phonics in learning to read). A second implication is that students should be taught to understand how chunking facilitates their learning and instructed in applying effective chunking techniques across various subjects and disciplines to enhance their academic success.

Not all cognitive load should/can be avoided

When reading a challenging book, a student faces a certain level of cognitive load generated, for instance, by unfamiliar vocabulary. It is called intrinsic cognitive load - linked to the learning task itself. This load can be adjusted, such as by matching the book difficulty to the learner's skills, preteaching, or building background knowledge. Simultaneously, a child shouldn't have to contend with issues like poorly formatted text, unclear fonts, or unnecessary distractions (e.g., TV). These are examples of extraneous cognitive load that should be minimized or avoided. This kind of load hampers learning by overwhelming working memory and often arises in badly designed apps or multimedia with cluttered or confusing interfaces. It can be also created by confusing instruction. Finally, germane cognitive load is a concept referring to the mental effort used to process new information, linking it with prior knowledge, and constructing deeper understanding and schemas. In reading, writing, and learning overall, germane cognitive load is pivotal. For example, when a reader encounters new information, germane cognitive load, created through note-taking, summarising, paraphrasing, and developing flashcards or mind maps, aids in forming connections between this new knowledge and the reader's existing schema or prior knowledge.

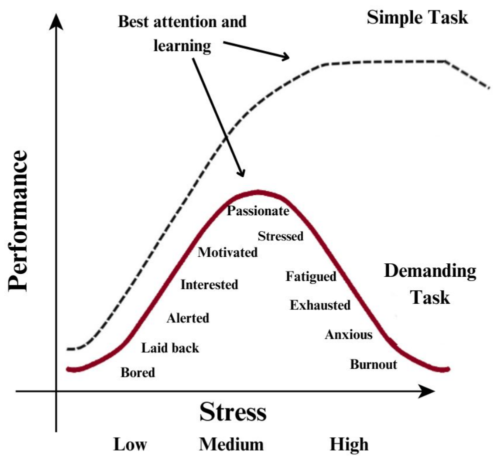


Types of cognitive load

A few words about stress in learning

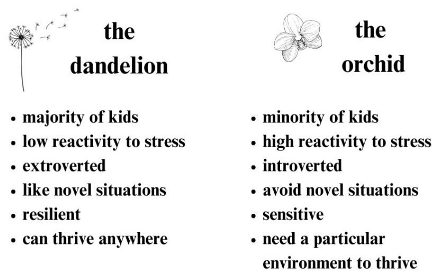
Excessive stress and anxiety often impede the learning process. Stress can overload students' working memory, as they must simultaneously process new information and cope with negative or intrusive thoughts or events, such as the fear of failure and its consequences. Also, high stakes (e.g. standardised assessment), the presence of an examiner, unfamiliar settings, and certain exam formats (e.g. oral exam) can add to cognitive load. Consequently, stress can hinder the encoding, retrieval, and retention of information, leading to difficulties in learning and more mistakes. Still, the relationship between stress and learning is complex and some level of 'good stress' (eustress) appears to benefit learning. A student who is disinterested and inactive does not learn effectively. Arousal, on the other hand, improves attention and the speed of processing. Arousal is heightened when a student is interested in or passionate about a subject. For instance, a student who notices the existence of a gap in their knowledge might feel a certain level of positive learning stress. Additionally, when a student faces a positive learning challenge, they experience some degree of stress, which can be beneficial for learning.

The Yerkes-Dodson law, a psychological principle that describes the relationship between stress (arousal) and performance, shows that performance increases with arousal, but only up to a certain point. Once arousal becomes too high, performance begins to decline. Interestingly, stress can help in simple learning situations when focused attention is required, while it is detrimental to learning in complex learning contexts when divided attention and multitasking are required.



Yerkes–Dodson Law illustrates the relation between stress and performance. Adapted from Diamond et al. (2007).

Stress does not impact all students in the same way. Some students are more sensitive to stress than others (see the Orchid-Dandelion model below). . The effects of stress on learning are also dependent on the learning context, personality traits, such as introversion or extroversion, working memory capacity (with weaker working memory affected the most), mindset, and successful experiences in dealing with stressful situations. Students usually cope with stress better when they have experienced intermediate levels of cumulative stress in their lives (rather than too little or too much stress).



The orchid-dandelion model (Boyce, 2019) is a framework used to describe the different sensitivities and responses of children to environmental influences. According to the model, 'dandelion children' are more resilient and can thrive in various environments, while 'orchid children' are more sensitive and can flourish under optimal conditions but may struggle in challenging or adverse environments.

Here are some recommendations:

- Parents need to understand and consider the level of stress that the child is experiencing. The learning environment needs to be managed by balancing challenges and support according to the child's needs and knowledge/skills. Challenging learning should occur in a relaxed and safe environment. Since stress cannot always be eliminated, it's important to provide children with coping strategies (discussing stress, mindset, getting enough sleep, practicing deep breathing, and engaging in aerobic exercise).

'Smart drugs'

I never anticipated having to delve into the topic of 'smart drugs' in this book, but recent conversations with both candid students who use such drugs and concerned parents have forced me to do so. To begin, what exactly are 'smart drugs'? Termed as cognitive enhancers or nootropics, these substances are believed to augment cognitive functions like memory, concentration, and motivation. Some of these drugs, like Ritalin and Adderall, have been specifically designed and approved to manage ADHD under the supervision of a healthcare professional. In this context, I aim to briefly discuss these drugs as they relate to students without ADHD. The primary inquiries I frequently encounter regarding 'smart drugs' are: (1) Do they genuinely enhance cognitive performance? (2) Are they safe? I could start answering these questions with a cautionary tale from my own family: a nephew took these drugs to excel in university exams, only to end up in a hospital and ultimately drop out of university.

But let's ignore this anecdotal story and focus on what research says about these drugs. As is often the case in research, opinions are divided. Yet, a slowly emerging consensus suggests that 'smart drugs' might indeed improve attention, concentration, motivation, and increase wakefulness. Unfortunately, there are several important caveats. First, studies also suggest a decrease in accuracy and efficiency, despite a significant increase in study time and effort. 'Smart drugs' don't appear effective in tasks requiring complex cognitive abilities, such as critical reading, academic writing, complex exams, and tasks requiring creativity and flexibility. In other words, they don't make students smarter; they seem to make them work harder. Second, although some of the smart drugs seem to help children with ADHD, for those without attention deficit issues, there might not be noticeable benefits and, sometimes, adverse reactions. Adding these drugs to a perfectly functioning attention span is similar to adding more fuel to a car; it will not make it run faster. In terms of safety, the long-term effects remain unclear due to limited scientific research. Potential side effects may include insomnia, irritability, anxiety, and high blood pressure. Also, these drugs may lead to dependency over time. Of course, there are also ethical and legal concerns since some of these substances are unregulated or illegal. In the context of university students, they seem to be often combined with alcohol or other substances, which is understandably a very bad idea. In summary, although 'smart drugs' might (just might) help some students in specific scenarios (e.g., last-minute cramming or all-nighters before exams or tests), considering the potential problems they are not worth trying. In my view, which should be clear through the pages of this book, true learning is a long-term process that cannot be rushed or enhanced with substances of this nature (at least not currently). If parents feel there might be valid medical reasons for it, they should always consult with a professional. I suggest the majority of parents focus on supporting children's attentional resources since they can be easily depleted (see Chapters 11 and 32). I also suggest having an honest conversation with teenage children about these drugs, their potential benefits, and their considerable risks since many older students, due to academic and peer pressures, might consider using them.

CHAPTER SUMMARY

- Although working memory cannot be directly improved there are several effective ways to support it. Children and parents need to understand the limitations of working memory and learn to circumvent them. Children and students should be explicitly taught about the brain and effective learning strategies.

- It is important to remember that children with poorer working memory are perfectly able to learn even very advanced material (providing cognitive overload is avoided). They simply learn it more slowly (particularly at the initial stages of learning) than children with stronger working memory. Although it can be very demotivating for both parents and children, the positive news is that this initially slow learning process usually speeds up.

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