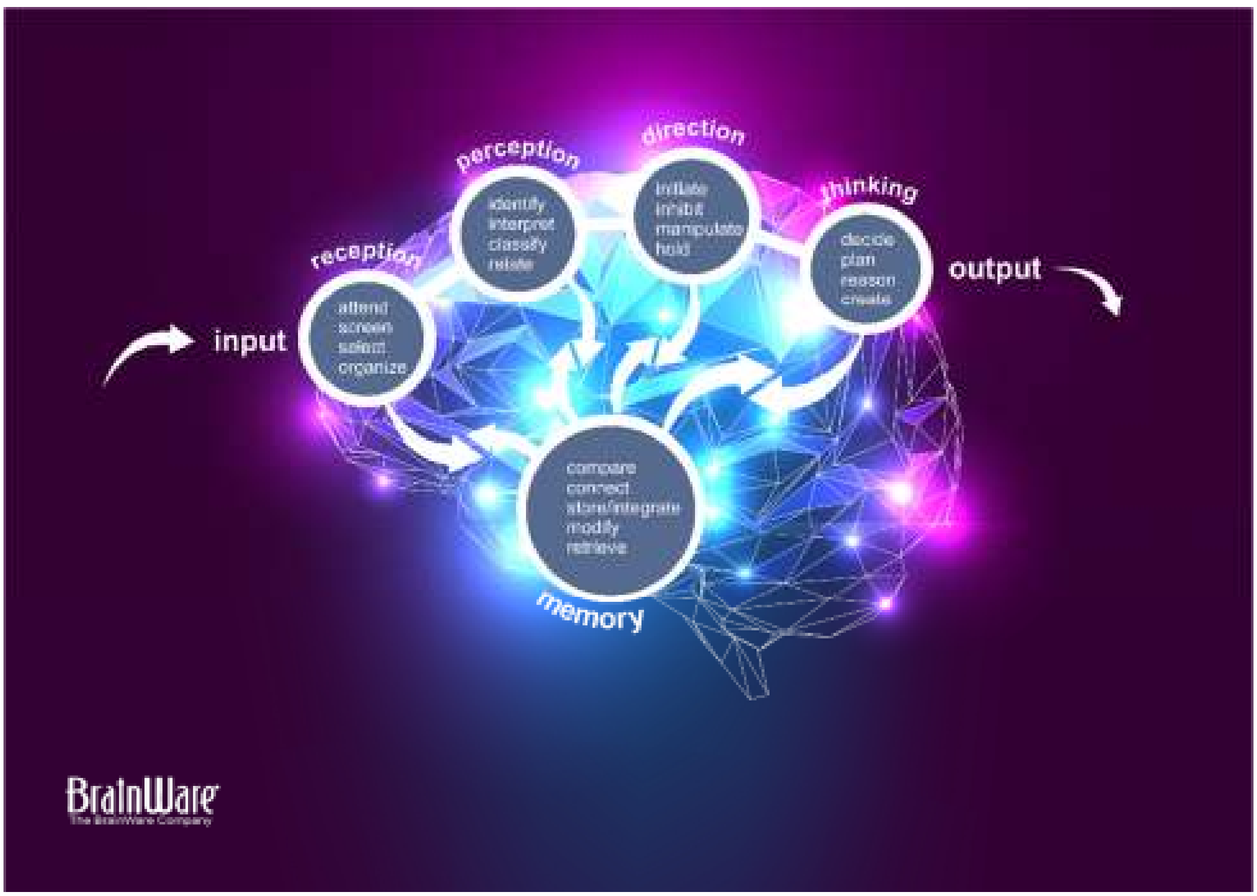
An Introduction to Cognitive Skills

Cognitive Skills: The Foundation for Learning

Cognitive Skills are the mental processes our brains use to take in, organize, understand, and retrieve information. So much of what happens in our brains are processes we aren't even aware of when they happen. But while they may happen non-consciously, they define our ability to learn. The model of cognitive processing in the image below will help explain what cognitive skills are and how they support the learning process.



Reception

At the first stage of the learning process, **Reception**, our brains are tasked with taking in information from the outside world. The enormous amount of information available to our senses must be compared, sorted, organized, and then filtered to eliminate irrelevant information and enable relevant information to flow through to other processes. Our brains take just fractions of a second to determine what is relevant and what to discard, and we are not even aware of it happening; this processing is all nonconscious. In order to do this we depend on cognitive skills such as various attention skills and the ability to efficiently gather visual inputs.

As information hits our senses, our visual and auditory processing skills predominate, particularly, visual processing. It is estimated that 80-90% of the information we take in is visual. The ability of our eyes to focus, coordinate, track, and how well they integrate peripheral vision with center vision (visual span), will have a lot to do with what information we actually take in. Our ability to retain the sequence of a set of instructions or distinguish between the words "liar" and "fire" can depend on the efficiency and accuracy with which our brains take in information.

When it comes to attention, there are different modes of attention – sustained, selective, divided and flexible attention. The first refers to how we sustain attention while we work on a particular thing. Selective attention refers to the ability to focus on one input without being distracted. Divided attention involves the ability to pay attention to two activities at the same time, such as taking notes while listening to the teacher. Good attention skills also enable us to move from one activity to another with ease and to focus on the most important information with which we are presented; for instance, to identify the key clues in a math story problem.

Once our brains have received inputs from the outside world, we need to give them meaning.

Perception

At the second stage of learning, **Perception**, our brains give meaning to the information coming into our brains through our senses. Information selected at the Reception stage is further processed to identify and interpret it. This requires retrieving stored information from memory and integrating it with the new information to identify a "table" or a "banana." . We must put visual and auditory information together, keep things in a sequence and understand where things are in space and time relative to other things. The ability to understand concepts like "behind," "on top of," and "next to," and "after," are examples of the time and space relationships that help us understand the world around us.

At the initial stages of processing, Reception and Perception, the cognitive processes occur within seconds and are performed largely non-consciously.

After our brains have taken in information, sorted it, organized it, and given it meaning, it is time for us to do something with it. Here, we can think about having read a sentence out loud, having made sense out of the words, but still needing to figure out what to do about it all.

Direction

The directive capacities of our mind are now generally referred to as Executive Functions (**Direction**). There are three core executive functions that we use to direct our minds. One is working memory, the ability to hold information in our minds while we manipulate it. Working memory is the conscious processing capacity of our minds. It is how we compare information we are reading to what we already know (the essence of comprehension), and how we keep track of where we are in solving a math problem.

A second executive function is inhibitory control, that is, our ability to stop ourselves from doing somethings we otherwise would do – like blowing out the candles on the birthday girl's cake. It is also what enables us to defer gratification over a period of time.

The third core executive function is cognitive flexibility. This is the lifeblood of learning. Our ability to change how we think when the world around us changes is cognitive flexibility. As we move through life, we frequently need to or shift from an external focus to internal reflective thinking Think about the kind of cognitive flexibility that it took to adjust to the idea that the world was round, not flat!

Memory

Memory is essential in all phases of information processing and is integral to any ability to manipulate information, compare, comprehend, and learn. In fact, if we can't remember something, we can't really say that we have learned it. Memory skills range from immediate to long-term depending on the duration of time information is stored. The only stage at which we are conscious of the information is when we are holding it and manipulating it in working memory. It is important to recognize that if we don't actively process information in working memory, it is unlikely to be stored in long-term memory. Long-term memory refers to our abilities to permanently store information and retrieve it when needed such as math facts, locker combinations or grammar rules. Research has shown that there are different types of long-term memory and that memory for procedures (like riding a bike or tying your shoes) is quite different from memory for events and facts (like what you ate for dinner last night and when your anniversary is). Short-term memory is subconscious memory, where the brain decides what information to discard or what to retain in working memory, within 1/1,000 of a second. Sequential memory refers to the ability to recall a sequence of information, in order, such as remembering the historical series of events leading up to the Revolutionary War or what happened at the beginning, the middle and the end of a story.

Thinking

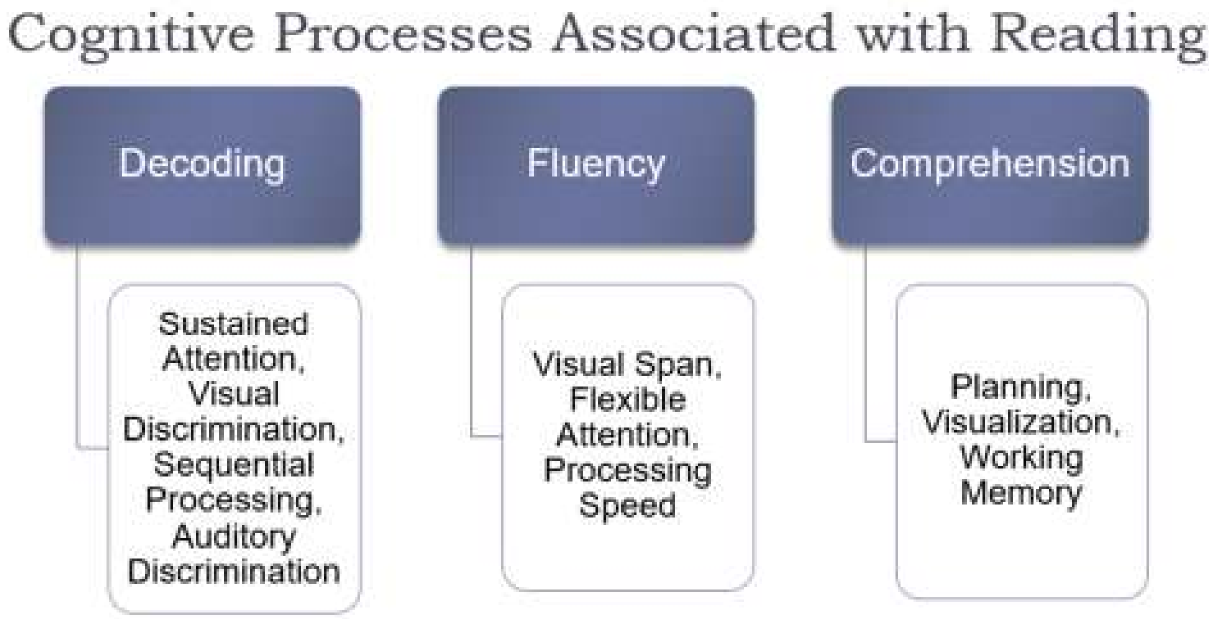
Critical thinking, reasoning, problem-solving, planning, decision-making and a host of other higher-order thinking processes are the culmination of the learning sequence. Having learned something means that we must take an action, make a decision, or somehow change our behavior. These skills, in which information is manipulated and applied, include such processes as planning, for example, how to tackle a multipart science experiment; concept development such as deductive reasoning; and the ability to use thinking skills quickly to make correct decisions such as in responding to questions on a test.

Cognitive Skills and Reading

As the foundation for learning, cognitive skills are essential in reading, math, writing, science, technology, engineering, arts, and any other academic discipline we could name. The essential role of a variety of cognitive processes and their direct impact on academic performance is supported by a growing body of evidence. In this article, we will consider the role of cognitive skills in reading.

What are the true basics of reading?

When educators are asked what the basics of reading are, the answer is typically **decoding and fluency and comprehension.** And indeed, these are vital skills; we can't be good readers without them. But they are not the true basics. The following image lists some of the basic cognitive skills which are essential to be able to perform the basics of reading. That is, these cognitive processes are prerequisites for and directly involved in reading.



There is, in fact, no decoding part of the brain. In fact, in order to decode words – to associate a phoneme (language sound) with a symbol (visual representation, letters) – our brains need to create a pathway and communication between parts of our brains that are not otherwise connected in this way. Our brains evolved for spoken language, but not for reading, so we co-opt existing systems (an area towards the back of the brain called the Visual Word Form Area and the brain region responsible for spoken language, called Broca's Area) to be able to read.

In addition to developing and activating this connection, reading necessitates that our brains also simultaneously engage a variety of other cognitive processes in order to **decode words**, including:

- Sustained Attention. If our minds go wandering off part way through the word or between words, so that we have to start it again, decoding is going to be impeded.
- Sequential Processing. If we can't keep the letters in the right order or the words in the right order as they enter our brains, this will also impact decoding.
- Visual Discrimination. The ability to distinguish a "b" from a "p" or an "m" from an "n" is something our brains must do in fractions of a second for decoding to be successful.
- Auditory Discrimination. The ability to distinguish the sounds of the language is also vital to reading, since otherwise they cannot be correlated to their written representations, and we can't hear the word we're trying to decode to determine if what we are saying corresponds.

Not only are all these cognitive processes essential for decoding, they all have to be working together at the same time in a coordinated, well-integrated fashion. Of course, other cognitive skills may be active for decoding; the purpose here is simply to explain the involvement of some of the most important skills required for decoding.

When it comes to building **fluency,** we rely on practice. Practice is needed to build the automaticity of pairing symbols and sounds and the expansion of one's repertoire of sight words. A variety of other cognitive processes will play a role here as well.

- Visual Span. This refers to how much information one can take in at a glance. Technically, it involves the coordination of peripheral and center vision, but from a practical point of view, it

can mean the difference between reading word by word and being able to take in groups or lines of words.
- Flexible Attention. In the context of reading, this affects the reader's ability to shift smoothly between words or lines or paragraphs. It is also, importantly, utilized in shifting mindsets back and forth between decoding and recognizing sight words.
- Processing Speed. Even when an individual is able to decode words accurately, processing speed affects reading efficiency and, therefore, the ability to build fluency.

The last "basic" of reading is no more "basic" than the other two. **Comprehension** is why we learn to read in the first place, but it often eludes students even when they have conquered the decoding process and built up reasonable fluency. Teachers and students struggle with this, school year after school year. Here, it will be helpful to highlight three cognitive skills that can help or hinder the process of trying to understand something we read.

- Working Memory. Working memory refers to our ability to hold information in our minds while we manipulate it. Working memory capacity is highly correlated with reading comprehension (and many other academic and non-academic outcomes). When we read a text, we accumulate pieces of information which we hold in our minds; this process happens in working memory. When we consciously think about how the information relates to our prior knowledge, which is how we create meaning, this also happens in working memory. When we encounter a word or a concept with which we aren't familiar, we may have to stop and figure it out from context, look it up or ask someone. Our ability to add that to what we're already holding in our minds about our text happens, again, in working memory. If working memory is weak, comprehension will be a significant struggle.
- Visualization. Visualization refers to our ability to create a mental picture of something we are reading about. It may not be a picture of a physical object; it could be relationships among things or characters. It could be a sort of mind-map, but it takes advantage of the capacity of our visual processing system to create a stronger memory that we can later retrieve.
- Planning. As students become more proficient readers, they will learn that there are many ways to read and understand a text. For example, we may read for a specific piece of information (what time to meet the bus for the field trip). We may read another text for the gist or to gauge the emotional tone. Or we may read slowly and deeply, trying to commit a mass of information to memory or grasp a complex concept. The ability to plan our approach to reading will help us be effective and efficient readers.

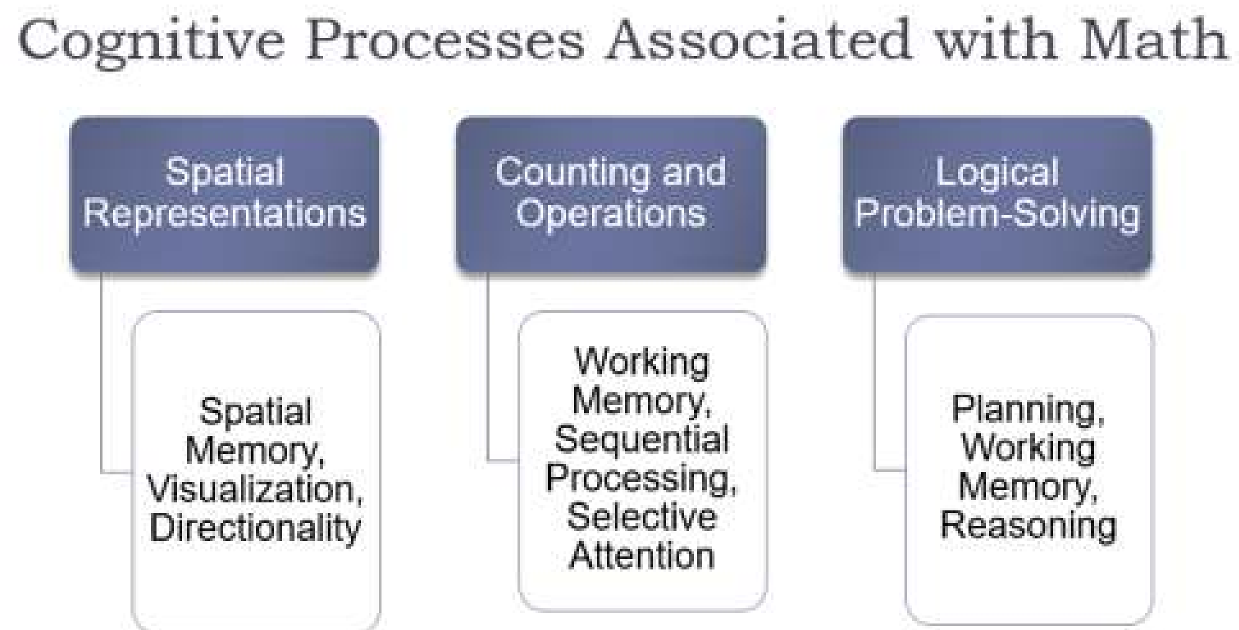
The importance of cognitive skills in reading has been underscored by a recent report from Digital Promise, a nonprofit organization working at the intersection of researchers, entrepreneurs, and educators, recently published a report entitled Supporting the Research-Based Personalization of Reading Success. The report cites cognitive skills, social-emotional learning, and student background information, in addition to traditional language and literacy skills, as essential for reading.

Of course, similar principles apply in math, and we'll address those in a subsequent article. There we will find that, since we don't have two brains – one for reading and another for math – many of the same skills discussed above will prove to be essential for math as well.

Cognitive Skills and Math

As the foundation for learning, cognitive skills are essential across the curriculum, including math and other STEM fields. However, math comprises so many different topics and levels of complexity that it is a challenge to address comprehensively, and indeed that there is much that continues to elude scientific consensus in characterizing how math works in the brain. It may seem like a stretch to say that the same mental processes are involved in basic math concepts like counting, and more advanced topics like algebra and calculus. In fact, most of us can't remember learning to count, but most of us will remember learning long division, or geometry, or algebra or calculus.

What, then, are the important underlying cognitive processes that support or impair our learning of math? While there are undoubtedly many ways of dividing up math topics, the following illustration groups math skills into an order that seems to fit with our understanding of key findings from scientific and educational research.



The relationship of math success to visual-spatial abilities is strongly supported by research, and the correlation actually appears to increase as the complexity of the mathematical task increases. The important aspect of visual-spatial processing is not just remembering the shape, size and color and number of objects, but their relationships to each other in space. It turns out that visual memory by itself (what things are) is somewhat error-prone, but spatial memory (where things are) is associated with correct answers, and is thus an important aspect of mathematical problem-solving. Within visual-spatial processing, we can distinguish cognitive skills such as the following:

- Spatial Memory. This refers to our ability to remember where we are in space and where we are related to other objects in space. This understanding provides the foundation on which problems (changes in the space) can be solved.
- Visualization. Our ability to visualize a problem we are considering or to visualize alternative solutions contributes substantially to our understanding of the problem. When we learn transformations in geometry, for example, interpreting the difference between a translation (sliding an object along a straight line), a rotation (turning an object around a point) and a reflection (mirror image) is greatly aided by our visualization skills.
- Directionality. The ability to distinguish left and right, of course, is more than about math. It comes in handy when tying shoes, reading a map or a chart, and in executing a football or basketball play. It is critical in chemistry (where two molecules may differ only in the orientation of the atoms (the technical term is "enantiomer")), but have two completely different uses (like

one drug used to treat tuberculosis whose enantiomer causes blindness). While we don't all deal with chemistry on a daily basis, we do often have to navigate unfamiliar territory. Imagine someone just handed you a map with a route traced on it. Do you have to keep turning the map around to figure out what direction to turn next? If so, your directionality skills are not as strong as they might be.

When it comes to counting and numerical operations, we are again dependent for math success on some foundational cognitive skills, such as sequential processing and selective attention, and on executive functions (the directive capacities of our minds) such as working memory.

- Working Memory. As explained in our previous article, working memory refers to our ability to hold information in our minds while we manipulate it. Working memory capacity is highly correlated with reading comprehension, with math performance, and with many other academic and non-academic outcomes. Working memory serves math processes from the very simple (for example, keeping track of which apples in the basket we've counted and which we haven't) to the most complex reasoning and mental simulations we perform when calculating statistics or contemplating string theory or manipulating derivatives in calculus.
- Sequential Processing. Counting, of course, is all about sequences, so once again, cognitive skills contribute crucially at even the most elementary stages of math. As we start to manipulate and calculate, the sequence of steps to solve a problem must be observed. A concrete example is the concept of order of operations and the different result that comes from (6 + 5) X 2 and from 6 + (5 X 2).
- Selective Attention. When we have good selective attention, we can more easily screen out the irrelevant parts of a complex problem and isolate the pertinent facts that we need to concentrate on. If Mary, who is wearing a red dress, is 3 years older than John, who is wearing a blue shirt and jean and just celebrated his 10^{th} birthday, we don't need to know the color of their clothes to determine how hold Mary is.

Finally, math is problem-solving. There are other types of problem-solving, of course, but problems with numbers almost always call for mathematical thinking and logic. In the discussion above, we have already highlighted some of the cognitive skills we use for problem solving, but higher-order cognitive processes are often required to be successful in math. And here we can start with Planning.

- Planning. When giving examples of cognitive skills at work, I often head to the most basic example I can think of. In this vein, a vivid memory of elementary school comes to mind; perhaps you have had a similar one. I am learning long division. I am supposed to carry out my solution to some number of decimal places. I write the problem on my paper and then, halfway through, I realize that I wrote the problem too far to the right on the piece of paper. That was a lack of planning. Good planning is in evidence when we consider alternative approaches to a problem, map out the sequence of steps in advance, and then carry them out efficiently and accurately.
- Working Memory. Here again, I think of a basic example. A fourth-grade girl in a school we were working with struggled with finishing her math assignments. She understood the core concepts of the computations she was being asked to do, but she had limited working memory capacity. When she needed to copy a problem from her math book onto her assignment paper, say,

$$\begin{array}{r} 138 \\ \underline{\times\ 64} \end{array}$$

she would have to copy each number by itself, first the 1, then the 3, and so on. She could not remember 138, much less the entire problem. (I am happy to report, that after she started a cognitive training program, she got to the point where she could remember the entire problem accurately – she and her mother celebrated with ice cream.) It should be obvious by now that working memory is essential to hold the elements of any problem in mind, consider different approaches, and keep track of where we are in a sequence of steps to solve a multi-step math problem.

- Reasoning. Ultimately math is logical and will put demands on our reasoning skills, as well as help us develop our reasoning skills. As we learn to derive theorems or explain how we draw conclusions (deductively or inferentially), we have to recognize patterns, analyze cause and effect, test hypotheses and determine whether to include or exclude items from sets. For all of these, logic is essential.

As is the case with reading, our cognitive skills must work together in complex and integrated ways. An article in Misunderstood Minds summarizes the process clearly,

> "For children to succeed in mathematics, a number of brain functions need to work together. Children must be able to use memory to recall rules and formulas and recognize patterns; use language to understand vocabulary, instructions, and explain their thinking; and use sequential ordering to solve multi-step problems. In addition, children must use spatial ordering to recognize symbols and deal with geometric forms…. Often several of these brain functions need to operate simultaneously."

Of course, there is significant overlap in the cognitive skills needed for reading and math. It bears repeating that we don't have two brains; we just have one, and we use it for reading and math and everything else we do.