Information Processing Theory

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The information processing theory of development compares the functioning of human brains to that of computers. Our short-term memory is compared to the processor of the computer, and our prodigious long-term memory store to the hard drive. This theory is a cognitive developmental one that views development as a continuous process. It attempts to explain the processes which our brains use to learn as we take in information from the environment and try to make sense out of it. Stimuli perceived by our senses are worked on by processes in the brain, determining what the reaction or output is. Information processing theorists describe information as flowing through 3 stages of memory and processing in the brain: the sensory register, short-term or working memory, and long-term memory. They theorize that how we respond to stimuli depends on the mental strategies that we use on information as it moves through these 3 parts. Information gets filtered along the way, and what gets stored in short-term and long-term memory is influenced by our cognitive ability, level of attention, and use of strategies like repetition and rehearsal (Lawless et. al, 2019). Gains in working memory capacity and processing speed in children and adolescents pave the way to increased cognitive ability, and deficiencies in either area can have a detrimental impact on learning and development. Information processing theory struggles in some areas, since the analogy of a brain to a computer fails to account for things like environmental influences and emotion, and human long-term memory is essentially limitless as compared to finite computer memory (Berk, 2018).

History

Information processing theory was first proposed by American psychologists like George Miller in the 1950s (Lawless et. al, 2019). A major advance in information processing theory occurred in 1968, when American psychologists John William Atkinson and Richard Shiffrin proposed the 3-stage model of memory. Their multistore model of memory described the process of memory formation and how stimuli were processed, moved to short-term memory, and ultimately long-term memory if the conditions were right. They envisioned a linear process, with information passing through the stages and being acted on by cognitive processes in the brain. This drew the inevitable parallel to the way computers work, with their linear process of input, processing by various programs and algorithms, and output (McLeod, 2012).

Sensory Memory and Sensory Register

Formation of memories begins with perception of things that are happening around us. Our senses are constantly bombarded with information in the form of stimuli from our surroundings. The brain cannot perceive and react to every stimulus, there is a filtering process that causes some information to be unconsciously ignored. Imagine someone driving a car down the road. There is a huge amount of stimuli and input that the senses take in, but not very much of it is needed to be able to safely drive. The unimportant stimuli, like trees, power lines, number and size of houses and the cars in their driveways, or people walking in a park is just the tip of the iceberg as relates to what our brain filters out. If the brain actually had to take in all of the stimuli it encountered, it would rapidly be overwhelmed. Researchers theorize that the brain has processes that unconsciously filter information that it has learned is not important or necessary to carry out the current task. While driving, it means our attention focuses on stimuli like traffic lights, cars moving around us, or slowing down and speeding up to stay in the flow of traffic.

Information that is perceived enters the sensory register, also known as sensory memory. The sensory memory is a temporary storage spot for all of the sensory input that we take in.

Sensory memory is thought to be broken up several categories, including visual, auditory, and haptic. Visual is also referred to as iconic memory, and is where what people see gets stored. Visual sensory memory is only thought to last for about ½ a second. This could be because the visual information is extremely vivid. It is essentially a fleeting glimpse of visual information in the surroundings that lasts just long enough to be moved into short-term memory if information processes cause it to. Auditory sensory memory, what we hear, is also called echoic memory, and lasts for up to 3-4 seconds. Haptic memory is tactile memory, containing information about things we have touched. Tactile memories last for up to about 2 seconds in the sensory register. The exact reason why the different types of sensory information are retained for different periods of time in the sensory memory is unknown (Cherry, 2020). For information to pass from the sensory memory stage to the short-term memory stage, it must be attended to. This happens by consciously focusing on specific stimuli in our surroundings, and moves information to short-term memory where it can be further acted upon by mental processes ("Sensory Memory", 2019).

Short-Term Memory

Information that passes into short-term memory can have several different fates. It could be filtered out and discarded or worked on by mental processes and moved to long-term memory. Short-term memory is described by some researchers as working memory, but the two aren't universally agreed to be the same thing. Some make the distinction that short-term memory is simply retained information, while working memory encompasses all of the temporary information and processes by which it is manipulated and thereby includes short term memory. The amount of information that working memory holds is limited. Information in working memory is only stored temporarily, and manipulated by processes in a way that allows cognitive processes like reasoning to occur (Berk, 2018). Short-term memory is thought to have a duration of up to 15-20 seconds. The number of pieces of information, or chunks, that can be stored and worked on in working memory at once varies, depending on the age of a person and on their cognitive ability. Research shows that children have smaller working memory capacities than adults (Gilchrist et al., 2009). From childhood to adulthood, the working memory capacity increases from about 2 items to about 7 items in a digit span task, in which participants are read a series of numbers and asked to repeat them back. As working memory capacity increases, more complex problems and cognitive processes can be carried out (Berk, 2018).

Working Memory

Alan Baddeley and Graham Hitch theorized that working memory was made up of a central executive system, and two distinct storage systems: the phonological loop and the visual sketchpad. This multicomponent model for working memory differed from previous views that short-term memory was simply storage for information, and not involved in any manipulation or cognitive processing of the information. Baddeley and Hitch performed experiments in which people performed cognitive tasks like reasoning and learning at the same time as holding strings of digits in their short-term memory. Their rationale was that if short-term memory did function as “working memory”, having it full of chunks of information should interfere with mental processing. They found that processing time was slower as the string of digits increased, but that the rate of errors in cognition did not increase noticeably. They inferred from this that the brain was able to perform cognitive tasks at the same time as it held other distinct information in short-term memory. These results led them to their multicomponent model in 1974 (Baddeley & Hitch, 2013).

The Dichotic Listening Test gave some additional insight into the way working memory is set up. Researchers put headphones on research participants, and played different sounds into each ear. Participants were asked to pay attention to one specific ear, and then were asked afterward if they had any memory of what sounds had been played into the ear they weren't asked to focus on. They were largely unable to give any information about the auditory content played for the unfocused ear. This demonstrated to researchers that people are not really capable of doing 2 auditory tasks at the same time. However, people are fully capable of performing a visual and an auditory task at the same time, like when someone talks on the phone while they drive down the road. This lent support to the validity of the multicomponent model for working memory (khanacademymedicine, 2013).

The Central Executive

The central executive is thought to be of central importance to the working memory system. Baddeley thought of the central executive as the coordinator of cognitive activity ("Central Executive", n.d.). It is the conscious part of the working memory and allows people to selectively pay attention to some information, and discard other pieces of information. In addition to giving people the ability to focus their attention selectively, the central executive also lets people switch what they are paying attention to from one task to another, or even divide their attention between multiple tasks at the same time. It is also thought to serve as a link between information that is being manipulated in working memory and existing memories in long-term memory. This last role is extremely important, since it affects the understanding and integration of new information into permanent memory ("The Central Executive System", 2015). Problems with being able to adequately filter out unimportant information are evident when studying the behavior of people that have ADHD. Excessive amounts of unimportant information cramming constantly into working memory can make it hard to concentrate on their intended task. This can make it much tougher to see their way through to solving complex tasks.

Components of Working Memory

Phonological Loop

Baddeley theorized that the central executive oversaw and coordinated working memory and the 2 subparts of working memory: the phonological loop and the visuospatial sketchpad. Once information has made it through the filter of selective attention and into working memory, it is compartmentalized based on the type of information that it is. The phonological loop is theorized to be the acoustic and verbal part of working memory, responsible for storing verbal information. It is important in helping people learn new words and languages, and described as being made up of 2 parts. The first is the phonological store, which holds spoken words in memory for a few seconds. The other part of the phonological loop is the articulatory control process. This is the part associated with speaking, and it is believed to be used to "rehearse" words and verbal information that are in the phonological store (McLeod, 2012). The phonological loop is thought to be important for children in learning vocabulary, as well as for adults when trying to learn a foreign language. Rehearsal of words in the phonological store keeps them in working memory longer, and gives cognitive processes more time to associate them meaningfully and permanently with other existing information in long-term memory. Use of conscious strategies like rehearsal is an effective method of encoding information we want to remember from the temporary storage of working memory to the permanent storage of long-term memory (Baddeley & Hitch, 2013).

Visuospatial Sketchpad

The second subpart of working memory that is coordinated by the central executive is the visuospatial sketchpad, which stores spatial and visual information. It is thought to be involved in a type of GPS system for people, keeping them alert to their exact position in relation to other objects around them as they move through the world. It is also believed that this system is able to retrieve visual memories and information from long-term memory and allow them to be used and processed in working memory. An example would be if someone asks you what color your neighbor’s house is. You probably answer by retrieving a visual memory of your neighbor’s house from long-term memory and analyzing it in your visuospatial sketchpad (McLeod, 2012).

Episodic Buffer

A third subpart of working memory has been theorized, which is called the episodic buffer. Researchers had noticed over time that the 3-part model of working memory (visuospatial, phonological and central executive) couldn’t always adequately explain how those parts interacted with long-term memory. The episodic buffer is characterized as another limited capacity system of storage. They describe the buffer as being able to handle information from both the visuospatial sketchpad and phonological loop at the same time, as well as information from long-term memory. In the buffer, multi-dimensional information from the different areas gets integrated seamlessly and allows chunks of data to be encoded into long-term memory (Baddeley, 2000).

The central executive decides which subpart to send information to. When conflicts arise the central executive functions to focus attention on certain tasks and information over others, and this inhibitory control is important when faced with difficult and complex situations. The overall capability and sophistication of the central executive increases as children age into adulthood, enhancing cognitive abilities and making it possible to solve tougher problems (Berk, 2018).

Long-Term Memory

Long-term memory is the last part of the information processing model. Depending on how well information is processed and manipulated in working memory, it may end up being encoded into long-term memory. Humans long-term memory capacity is massive, thought to be nearly unlimited. There are a variety of strategies that can be used to aid the encoding of information that is in the working memory into long-term memory. Focusing intently on information, making the conscious choice to give it attention, makes it more likely to be remembered. Repetition is another technique used to try to increase the chance of remembering something. Once information is stored in long-term memory, the problem becomes one of retrieval. Some knowledge and processes can become so ingrained and well-learned that they can be used without taking up space in working memory. An example is driving a car, in which many of the actions responsible for driving safely are done automatically without any conscious thought. This lets other information be manipulated in working memory while performing the "automatic process" like driving (Berk, 2018).

Long-term memory is divided up into a few different categories. Procedural memory is thought to store information on how to perform certain actions, or in other words how to "do things". This can encompass a wide variety of activities and abilities, from walking up a flight of stairs to swimming across a pool to riding a bike. Procedural memories are formed from very early on in life, and includes motor skills that will end up becoming so ingrained in our brain that we don't even have to think about them anymore. When you tie your shoe, you probably don't even think of all the individual steps as you perform the task. You simply tie your shoes, and have little recollection of the exact sequence of steps you performed in doing so. Walking is another example: you don't think about the myriad of things you have to do to walk in a coordinated and steady way down the street. Researchers think that performing motor skills like this one frequently over time strengthens the synaptic routes between neurons you use to accomplish them (Cherry, 2019).

Another category of long-term memory is explicit, also known as declarative, which itself consists of 2 parts: semantic and episodic. The information in semantic memory is general in nature, consisting of things like knowing that Maine is a state or that green is a color. Episodic long-term memory consists of our recollections about things that we have personally experienced and seen in our lives. Knowing that cats are a type of animal would be a semantic memory. Remembering playing with the family cat in our childhood is episodic memory, an autobiographical event we have in our brains. The context of episodic memories is frequently stored as well, like any particularly strong emotions we may have been feeling at the time (Cherry, 2019).

Working Memory Capacity and Intelligence

Working memory capacity (WMC) is believed to increase as children develop. Charles Spearman put forth the g factor theory, which states that the observed differences in intelligence between individuals can be explained by "g", or an underlying factor that all intellectual performance and ability arises from. Some researchers have looked into Spearman's theory as relates to WMC, and think that WMC could be the foundation of g. Their review of research showed that WMC and g were closely related, but could not definitively say whether the two are equal (Conway et al., 2003).

A group of researchers in 1990 set forth the idea that the observed differences in cognition between people are a result of several factors, including how much procedural knowledge they had, WMC, and processing speed. They stated their view that "working memory comprises the functions of focusing attention, conscious rehearsal, and transformation and mental manipulation of information," and that working memory closely related to g. While the exact role working memory and its capacity play in development and cognitive ability is not yet known, most researchers agree that it is an important piece of the puzzle (Colom et al., 2004). Another research group did a series of studies looking at the relative influence that working memory and processing speed had on the development of intelligence. They concluded that working memory "has a significant strong direct effect on intelligence" and furthermore that "WM is the best candidate for the cognitive process constituting the cognitive basis of intelligence" (Tourva et al., 2015).

Developmental Changes

In childhood and adolescence, gains in brain development occur that results in increased cognitive ability. Researchers have noted several changes that occur during this period to bring this about. Working memory capacity, as was noted earlier, generally increases as children age. Being able to hold more pieces or chunks of information in working memory at one time is a monumental change and allows adolescents to reason through and solve more complex problems. The actions of the central executive become more adept and capable. This includes achieving greater control over our ability to focus selectively on one specific thing, getting better at ignoring irrelevant data, and watching over how data is manipulated in the working memory (Berk, 2018).

Another important factor in development is a gain in processing speed. Faster processing speed allows faster solving of problems, since more information can be loaded into working memory and manipulated in a given time. Studies have shown that “processing speed increases lead to improvements in working memory, which in turn yield benefits in intelligence” (Chevalier et al., 2015). The myelination of neurons in the brain plays a role in the processing speed increase observed in children. Another study on a group of healthy elderly people found a correlation between myelin breakdown and slowed cognitive processing speed. The exact mechanism isn’t known, but myelination appears to play an important role for people of all ages in relation to how fast they process information, and to cognitive ability as a whole (Lu et al., 2011).

Conclusion

Information processing theory seeks to explain the way people think and learn, and how the brain processes information and forms memories. The analogy to being like the internal functioning of a computer, with our mental processes being analogous to the programs computers run to turn input into output, is both simple and elegant. Following the path a stimulus takes from initially being perceived to making its way into long-term memory is a fascinating voyage. The theory is more of a conceptual one though, doing a good job of breaking down the different parts of the mental processes that occur when we think and form memories. The theory also does little to take into account how factors like social context, emotion, and creativity affect learning and cognition. Researchers continue to delve into details of human cognition, and may someday be able to form a cohesive whole from the various elements that make up the model of information processing theory.

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