Information Processing Theory

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Humans process information with amazing efficiency and often perform better than highly sophisticated machines at tasks such as problem solving and critical thinking (Halpern, 2003; Kuhn, 1999). Yet despite the remarkable capabilities of the human mind, it was not until the 20th century that researchers developed systematic models of memory, cognition, and thinking. The best articulated and most heavily researched model is the information processing model (IPM) developed in the early 1950s. The IPM consists of three main components, sensory memory, working memory, and long-term memory (see Figure 1). Sensory and working memory enable people to manage limited amounts of incoming information during initial processing, whereas long-term memory serves as a permanent repository for knowledge. In this entry, the information processing model will be used as a metaphor for successful learning because it is well supported by research and provides a well-articulated means for describing the main cognitive structures (i.e., memory systems) and processes (i.e., strategies) in the learning cycle.

SENSORY MEMORY

Sensory memory processes incoming sensory information for very brief periods of time, usually on the order of 1/2 to 3 seconds. The amount of information held at any given moment in sensory memory is limited to five to seven discrete elements such as letters of the alphabet or pictures of human faces. Thus, if a person viewed 10 letters simultaneously for 1 second, it is unlikely that more than five to seven of those letters would be remembered.

The main purpose of sensory memory is to screen incoming stimuli and process only those stimuli that are most relevant at the present time. For example, drivers on a busy freeway in heavy traffic are constantly bombarded with visual and auditory stimuli. To maximize efficiency and safety, they process only information that is relevant to safe driving. Thus, they would attend to road conditions but not buildings they pass as they drive. Similarly, they would attend to sounds of other cars, but not to music from the radio or one passenger's casual conversation with another.

Researchers agree that information processing in sensory memory usually occurs too quickly for people to consciously control what they attend to. Rather, attention allocation and sensory processing are fast and unconscious. Information that is relevant to the task at hand, and information that is familiar and therefore subject to automatic processing, are the most likely types of information to be processed in sensory memory and forwarded to the working memory buffer. Information that is highly relevant may receive some degree of controlled, conscious processing if it is crucial to a task (e.g., attending to salient information such as animals along the road while driving at high speed). However, controlled processing in sensory memory would be likely further to reduce the limited amount of information that can be processed at any given moment.

WORKING MEMORY

After stimuli enter sensory memory, they are either forwarded to working memory or deleted from the system. Working memory is a term that is used to refer to a multi-component temporary memory system in which information is assigned meaning, linked to other information, and essential mental operations such as inferences are performed. A number of different models of working memory have been proposed (Shah & Miyake, 1999). However, the three-component model developed by Baddeley (1998, 2001) is the most common, and will be discussed shortly.

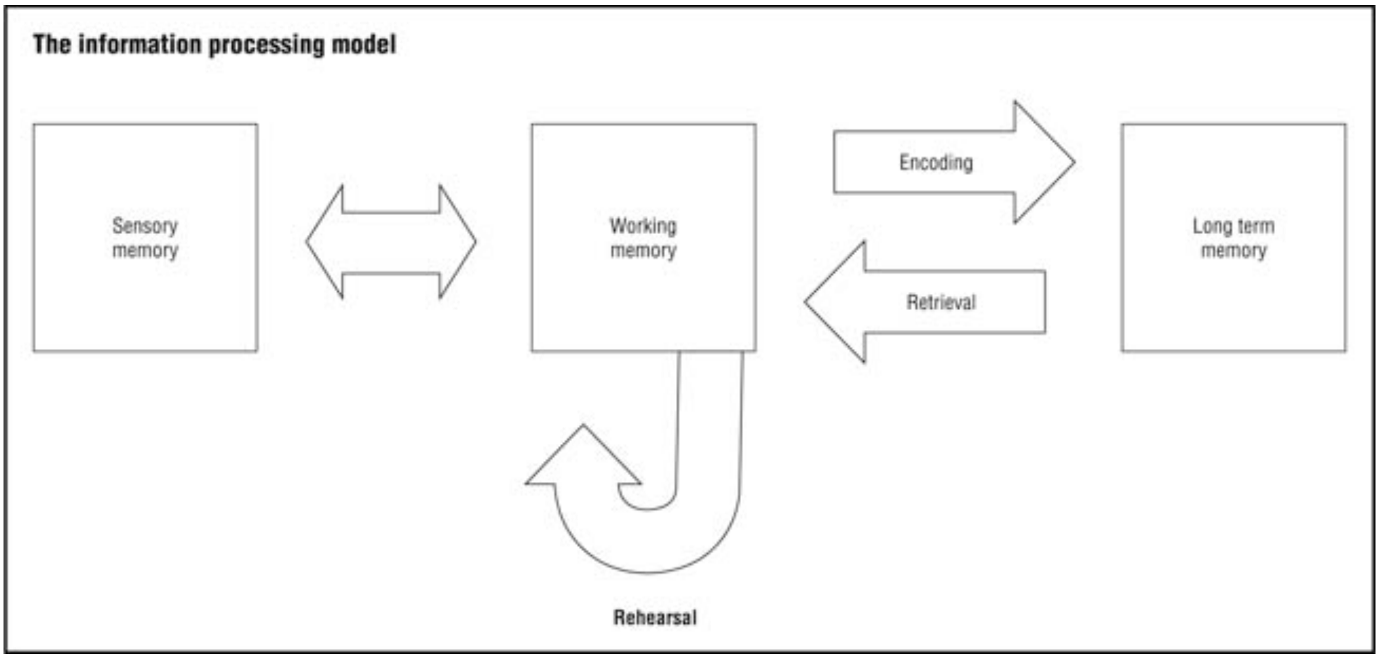

*Figure 1*ILLUSTRATION BY GGS INFORMATION SERVICES. CENGAGE LEARNING, GALE.

Several useful terms have been developed to describe efficient cognitive processing in working memory. One term is *limited attentional resources*, which refers to the highly limited nature of information processing (Anderson, 2000; Neath, 1998). All individuals experience severe limitations in how much mental activity they can engage in due to limited cognitive resources (Kane & Engle, 2002). Although humans differ with respect to available cognitive resources, all learners experience severe limitations regardless of their skill and ability level. Often, differences between one learner and another are not due to the amount of resources, but how efficiently those resources are used.

Another key term is *automaticity*, which refers to being able to perform a task very quickly and efficiently due to repeated practice (Stanovich, 2003). Automated activities usually require few cognitive resources; thus, even a complex skill such as driving a car at 75 miles per hour can seem effortless. Effective information processing in sensory memory requires a high degree of automaticity with regard to recognition of familiar stimuli such as spoken or printed words, faces, and sounds.

A third key term is *selective processing*, which refers to the act of intentionally focusing one's limited cognitive resources on stimuli that are most relevant to the task at hand. For example, when driving in snow, one might allocate more of one's limited cognitive resources to watching the center line in the highway than one would allocate on a clear summer day. In contrast, on an extremely windy day, one would pay little attention to the whereabouts of the center line but pay special attention to any flying debris that could cause an accident. In essence, selective processing enables learners to be optimally efficient by putting all of their cognitive eggs in one basket. It is no coincidence that highly effective learners succeed because they identify what is most important to learn and allocate limited attention to relevant information.

Baddeley's 2001 model of working memory consists of three components, the *executive control system, articulatory loop, and visual-spatial sketch pad*. The role of the executive control system is to select incoming information, determine how to best process that information, construct meaning through organization and inferences, and subsequently transfer the processed information to long-term memory or choose to delete that information from the memory system altogether (e.g., a telephone number that is no longer needed). Most models of working memory assume that the central executive is the place where humans "make conscious meaning" of the information they process (Shah & Miyake, 1999). The role of the articulatory loop is to maintain and further process verbal information. The role of the visual-spatial sketch pad is analogous to the articulatory loop in that it maintains and further processes non-verbal and visual information. Information is lost quickly from working memory (i.e., 5 to 15 seconds) unless some type of mental rehearsal occurs. Barring rehearsal (e.g., repeating a telephone number), information is either forwarded to long-term memory or is deleted from the system.

Baddeley's model makes several critical assumptions about the processing of information in working memory. One is that each of the three subsystems possesses its own

A comparison of sensory, working, and long term memory

Type of memory	Purpose	Capacity	Duration of retention
Sensory memory	Provides initial screening and processing of incoming stimuli.	3 to 7 discrete units	0.5 to 3 seconds
Working memory	Assigns meaning to stimuli and links individual pieces of information into larger units. Enables learner to construct meaning and perform visual-spatial mental operations.	7 to 9 units of information	5 to 15 seconds without rehearsal
Long term memory	Provides a permanent repository for different types knowledge	Infinite	Permanent

*Table 1*ILLUSTRATION BY GGS INFORMATION SERVICES. CENGAGE LEARNING, GALE.

pool of limited cognitive resources. This means that, under normal information processing circumstances, each subsystem performs work without taxing the other subsystems. A second assumption is that the executive control system regulates the articulatory loop and visual-spatial sketch pad.

LONG-TERM MEMORY

Unlike sensory and working memory, long-term memory is not constrained by capacity or duration of attention limitations. The role of long-term memory is to provide a seemingly unlimited repository for all the facts and knowledge in memory. Most researchers believe that long-term memory is capable of holding millions of pieces of information for very long periods of time (Anderson, 2000). A great deal of research has gone into identifying two key aspects of long-term memory: (a) what types of information are represented, and (b) how information is organized. These two questions are addressed in the next section of this entry. For present purposes, there is universal agreement that qualitatively different types of information exist in long-term memory and that information must be organized, and therefore quickly accessible, to be of practical use to learners.

Figure 1 shows that working memory and long-term memory are connected by *encoding* and *retrieval* processes. Encoding refers to a large number of strategies that move information from temporary store in working memory into long-term memory. Examples include organization, inference, and elaboration strategies, which will be discussed later. Retrieval refers to processes that enable individuals to search memory and access information for active processing in working memory. Both encoding and retrieval greatly facilitate learning when information in long-term memory is organized for easy access.

A comparison of the three components of the IPM indicates that both sensory and working memory are relatively short term in nature (see Table 1). Their main roles are to screen incoming information, assign meaning, and relate individual units of information to other units. In contrast, the main role of long-term memory is to serve as a highly organized permanent storage system. Sensory and working memory process few pieces of information within a short time frame. Automaticity of processing and selective allocation of limited cognitive resources greatly increases the efficiency of information processing. Long-term memory is assumed to be more or less permanent and unlimited in terms of capacity. The main processing constraint on long-term memory is the individual's ability to quickly encode and retrieve information using an efficient organizational system.

The information processing model provides a conceptual model which explains the different functions and constraints on human memory. The IPM also has had a major impact on instructional theory and practice. Sweller and Chandler's 1994 work developed *cognitive load theory* to explain how different instructional and learner constraints affect optimal information processing. The crux of their argument is that each task imposes some degree of cognitive load, which must be met either by available cognitive resources or learner-based strategies such as selective attention and automaticity. Reducing cognitive load enables individuals to learn with less overall mental effort. Cognitive load theory has been especially helpful in terms of planning instruction and developing learning materials. Others researchers such as Mayer and Moreno (2003) have developed frameworks to increase learning by systematically reducing cognitive load through better design of learning materials and more strategic use of limited resources by students.

In summary, the information processing model postulates a three-component model of information processing. The IPM is consistent with empirical findings and provides an excellent framework for understanding principles of effective learning, which are considered later in this entry. Sensory and working memory are limited with respect to capacity and duration, whereas long-term memory is more or less unlimited. Information processing efficiency is increased due to automaticity and selectivity. Encoding and retrieval of information in long-term memory is increased due to efficient organizational strategies.

IMPLICATIONS FOR INSTRUCTION

The information processing model provides four important implications for improving learning and instruction. The first is that memory stores are extremely limited in both sensory and working memory. The two main strategies that effective learners use to cope with limited capacity are selectively focusing their attention on important information and engaging in as much automated processing as possible. From an educational perspective, it is essential for students to become automated at basic skills such as letter and word decoding, number recognition, and simple procedural skills such as handwriting, multiplication, and spelling. Automaticity makes available limited processing resources that can be used to engage in labor intensive self-regulation (Butler & Winne, 1995; Zeidner, Boekaerts, & Pintrich, 2000; Zimmerman, 2000) and comprehension monitoring (Schraw, 2001; Sternberg, 2001).

A second implication is that relevant prior knowledge facilitates encoding and retrieval processes. Highly effective learners possess a great deal of organized knowledge within a particular domain such as reading, mathematics, or science. They also possess general problem-solving and critical-thinking scripts that enable them to perform well across different domains. This knowledge guides information processing in sensory and working memory by providing easy-to-access retrieval structures in memory. It also serves as the basis for the development of expertise (Alexander, 2003; Ericsson, 2003). Thus, helping students use their prior knowledge when learning new information promotes learning.

A third implication is that automated information processing increases cognitive efficiency by reducing information processing demands. As discussed earlier, automaticity is an important aspect of effective learning for two reasons. One is that being automated makes it easier selectively to allocate limited resources to information that is most relevant to the task at hand. Unfortunately, there is no easy road to automaticity other than sustained, regular practice. In addition, automaticity frees limited resources that can be used for other activities such as drawing inferences and connecting new information to existing information in memory.

A fourth implication is that learning strategies improve information processing because learners are more efficient and process information at a deeper level (Pressley & Harris, 2006; Pressley & McDonald-Wharton, 1997). All effective learners draw from a repertoire of learning strategies in a flexible manner. Some of these strategies are used automatically, while some require controlled processing and metacognitive control that place high demands on limited cognitive resources. Good learners use a wide variety of strategies and use them in a highly automatic fashion. However, there are three general strategies that all effective learners use in most situations. These include *organization, inferences*, and *elaboration* (Mayer & Moreno, 2003). Organization refers to how information is sorted and arranged in long-term memory. Information that is related to what one already knows is easier to encode and retrieve than isolated information. In some cases, individuals already possess well organized knowledge with empty slots that can be filled easily with new information. Activating existing knowledge prior to instruction, or providing a visual diagram of how information is organized, is one of the best ways to facilitate learning new information. Constructing inferences involves making connections between separate concepts. Elaboration refers to increasing the meaningfulness of information by connecting new information to ideas already known.

See also:Cognitive Development, Cognitive Strategies, Memory, Metacognition

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