**2**

# Information Processing and Memory: Theory and Applications[2]

Stacey T. Lutz and William G. Huitt

Educators are very interested in the study of how humans learn. This is because how one learns, acquires new information, and retains previous information guides selection of long-term learning objectives and methods of effective instruction. To this end, cognition as a psychological area of study goes far beyond simply the taking in and retrieving of information. Rather, the focus is on the holistic study of brain functioning and mind. Neisser (1967), one of the most influential researchers in cognition, defined it as the study of how people encode, structure, store, retrieve, use or otherwise learn knowledge. Cognitive psychologists hypothesize an intervening variable or set of variables between environment and behavior—which contrasts it with behavioral theories.

## Information Processing and Memory

One of the primary areas of cognition studied by researchers is memory. There are many hypotheses and suggestions as to how this integration occurs, and many new theories have built upon established beliefs in this area. Currently, there is widespread consensus on several aspects of information processing; however, there are many dissentions in reference to specifics on how the brain actually codes or manipulates information as it is stored in memory.

Schacter and Tulving (as cited in Driscoll, 2001) stated that "a memory system is defined in terms of its brain mechanisms, the kind of information it processes, and the principles of its operation" (p. 283). This suggests that memory is the combined total of all mental experiences. In this light, memory is a built store that must be accessed in some way in order for effective recall or retrieval to occur. It is premised on the belief that memory is a multi-faceted, if not multi-staged, system of connections and representations that encompass a lifetime's accumulation of perceptions.

Eliasmith (2001) defined memory as the "general ability, or faculty, that enables us to interpret the perceptual world to help organize responses to

[2] First appeared as Lutz, S., & Huitt, W. (2003). Information processing and memory: Theory and applications. *Educational Psychology Interactive*. Valdosta, GA: Valdosta State University.

changes that take place in the world" (p. 1). It is implied by this definition that there must be a tangible structure in which to incorporate new stimuli into memory. The form of this structure has been the source of much debate, and there seems to be no absolute agreement on what shape a memory structure actually takes, but there are many theories on what constitutes both the memory structure and the knowledge unit.

Winn and Snyder (2001) attributed the idea that memory is organized into structures to the work of Sir Frederick Charles Bartlett. Bartlett's work established two consistent patterns regarding recall. First, memory is inaccurate. This finding is not surprising or novel today, but its implications will be discussed later in this chapter. His second finding, though, brought about somewhat of a revolution in traditional thinking about memory. Bartlett suggested that the inaccuracy of memory is systematic. A systematic difference makes allowable the scientific study of inaccuracy, and this suggestion led to an entirely new mode of thought on memory. What accounted for systematic inaccuracies in memory were the intervening influences of previous information and the experiences of the person. This demonstrates that knowledge units are not simply stored and then left alone, but that they are retained, manipulated, and changed as new knowledge is acquired.

Despite disagreement on many levels, there is general agreement among most cognitive psychologists on some basic principles of the information processing system. First, there is the "assumption of a limited capacity." Depending on the theory, these limitations occur at different points in information processing, but it is widely held in all models that there are limitations as to how much and at what rate new information can be encoded, stored and retrieved (eg, Broadbent, 1975; Case, 1978) Most cognitive psychologists also agree that there exists an element of control system for dealing with stimuli (eg, Atkinson & Shiffrin, 1971). Again, exactly how and where the controls operate is a question of some debate, but the actuality a system that requires some processing capacity is generally accepted.

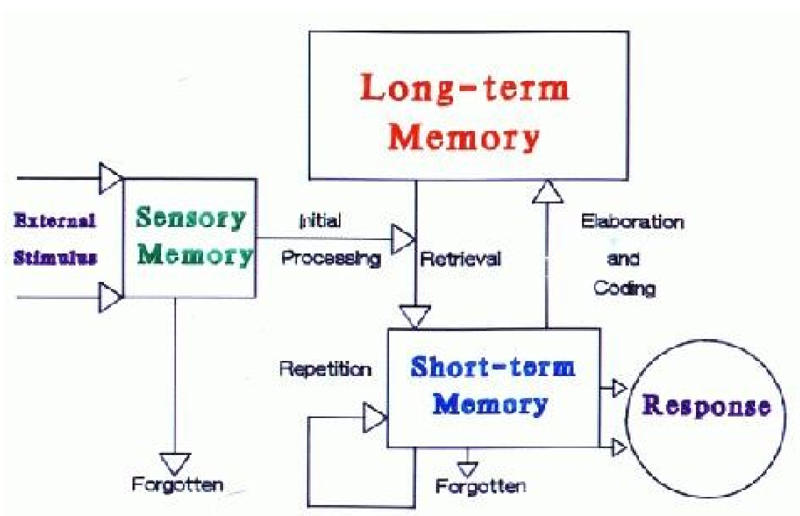
The belief in the interaction of new information with stored information is a third key point of cognitive study. This is usually demonstrated with a bottom-up or top-down system or a combination of the two. A bottom-up system is predicated on the belief that new information is seen as an initiator which the brain attempts to match with existing concepts in order to break down characteristics or defining attributes (eg, Gibson, 1979). A top-down system seems to suggest an opposite approach. The existing information is the initiator and memory representations are evaluated, then matched to the stimuli (eg, Miller, Galanter, & Pribram, 1960).

Finally, there is also agreement that humans have specific genetic traits that dictate the method by which they gain new information. For example, all human infants make the same vocalizations during the first six months, regardless of the language spoken around them (Flavell, Miller, & Miller, 2002). After that, infants begin to vocalize the sounds of the mother tongue and omit sounds not found in that language (Jusczyk, 1997). It has also been discovered that infants begin to lose the ability to discriminate sounds not in the mother tongue at about six to seven months of age (Werker & Tees, 1999). All of these factors play a significant role in the development and understanding of how the mind operates, but they are only the starting point, or maybe more accurately the dividing point, for more in depth models for information processing.

**The Stage Model**

Traditionally, the most widely used model of information processing is the stage theory model, based on the work of Atkinson and Shiffrin (1968). A key element of this model was that it viewed learning and memory as discontinuous and multi-staged. It hypothesized that as new information is taken in, it is in some way manipulated before it is stored. The stage theory model recognized three types or stages of memory: sensory memory, short-term or working memory, and long-term memory.

## Figure 2-1. A Stage Model of Memory




**Sensory memory**. Sensory memory represents the initial stage of stimuli perception. It is associated with the senses, and there seems to be a separate section for each type of sensual perception, each with its own limitations and devices. Obviously, stimuli that are not sensed cannot be further processed and will never become part of the memory store. This is not to say that only stimuli that are consciously perceived are stored; on the contrary, everyone takes in and perceives stimuli almost continuously. It is hypothesized, though, that perceptions that are not transferred into a higher stage will not be incorporated into memory that can be recalled. The transfer of new information quickly to the next stage of processing is of critical importance, and sensory memory acts as a portal for all information that is to become part of memory. This stage of memory is temporally limited which means that information stored here begins to decay rapidly if not transferred to the next stage. This occurs in as little as ½ second for visual stimuli and three seconds for auditory stimuli. There are many ways to ensure transfer and many methods for facilitating that transfer. To this end, attention and automaticity are the two major influences on sensory memory, and much work has been done to understand the impact of each on information processing.

While attention has been a focus of study for decades, there is still little consensus as to how it operates (Logan, Taylor, & Etherton, 1999). Treisman (as cited in Driscoll, 2001) "showed, however, that attention is not an all-or-nothing proposition and suggested that it serves to attenuate, or tune out, stimulation" (p. 81). Attention does facilitate the integration and transfer of the information being attended, but it is impacted by many factors including the meaningfulness of the new stimulus to the learner, the similarity between competing ideas or stimuli, the complexity of the new information, and the physical ability of the person to attend.

Automaticity is almost the exact opposite of attention. Driscoll (2001) said that "When tasks are overlearned or sources of information become habitual, to the extent that their attention requirements are minimal, automaticity has occurred" (p. 82). Automaticity allows attention to be redirected to other information or stimuli and allows for the ability of multi-tasking without distracting totally from the acquisition of new information.

There are several suggested models of how new stimuli are recognized in sensory memory, and each concerns pattern recognition. The matching of new stimuli to existing memory structures is a crucial factor in the acquisition of new knowledge. If new information is not brought into memory in a meaningful way, it will not be stored as memory. Therefore, the understanding of the patterns by which this information is represented is critical to the proper introduction of new information. Driscoll (2001) said that pattern recognition is "the process whereby environmental stimuli are recognized as exemplars of concepts and principles already in memory" (p. 84). She discussed three models of pattern recognition: template matching, the prototype model, and feature analysis.

The template matching model held that there are exact representations of previous stimuli trapped in the mind. Pattern recognition, then, occurs by matching input with a specific, perfect specimen stored in memory. This model seems to fall short because of the vast numbers of templates that would have to exist in memory for any one type of entity and because it does not account for imperfect stimuli or imperfect templates. The second pattern recognition model is the prototype. This model suggested that the stored unit is a generalized or abstracted form of the knowledge unit, and pattern recognition is based on a comparison of the input to the prototype. If a close match is established, new information can be accepted as the existing class. These two models are very similar in that they each attempt to match incoming information with a whole picture stored in memory. This holistic comparison differentiated them from the third model, feature analysis. In this system, incoming information is judged based on characteristics rather than a whole idea. Individual characteristics are picked out and then grouped to label the new stimulus as an "X". The major difference, simply put, is that these two perspectives seem to work in opposite directions, the first two from top-down and the third from bottom-up.

**Short-term or working memory**. The second stage of information processing is labeled short-term (STM) or working memory (WM). This stage is often viewed as active or conscious memory because it is the part of memory that is being actively processed while new information is being taken in. STM has a very limited capacity and unrehearsed information will begin to be lost from it within 15-30 seconds if other action is not made. There are two main ways that are effective in processing information while it is in short-term memory. Rote or maintenance rehearsal is the first but less desirable of these methods. This type of rehearsal is intended only to keep information until it can be processed further. It consists mainly of some sort of repetition of the new information and if it is not processed further will be lost. In fact, studies on the limitations of WM have revealed a specific number of units that the mind can process at any given time, and it is now generally accepted that 3 to 7 stimuli is the maximum number that can be processed at once. There are several types of activities that one can perform to encode new information, but the importance of encoding cannot be overstated.

Maintenance rehearsal schemes can be employed to keep information in STM, but, according to the stage theory, more complex elaboration is necessary to make the transfer to long-term memory. It is absolutely necessary for new information to somehow be incorporated into the memory structure in order for it to be retained. There are many suggested models for encoding, but there are basically three ways in which retention occurs. A stimulus can be an almost exact match with existing structures in which case it would be simply added to the mental representation and no change would be made to the structure except its addition. If the new stimulus does not exactly match the existing structure, the structure itself would be adapted to allow for additional characteristics or definitions in which case there would be a fundamental change to the existing structure, which would broaden the defining structures. Finally, if the new stimulus were vastly different from any existing structure, a totally new structure would be created in memory. This new structure could in some way be linked to relevant structures, but it would stand alone as a new unit. At any rate, the incoming information must be acted on and through existing structures and incorporated into those systems in some way for acquisition to occur. The processing of this new stimulus takes place in short-term memory, and the body of knowledge with which the information is integrated is the long-term memory.

The implications of this research are clear. If learning—relatively permanently change—is to take place, new information must be transferred into long-term memory. Therefore, repetition and maintenance rehearsal are not sufficient to produce a lasting effect. This has great relevance to instruction and teaching, for if the aim of education is learning, information must be presented in such a way that learners must work on it so that it can be incorporated into the memory structure.

**Long-term memory**. As discussed with short-term memory, long-term memory (LTM) stores all previous perceptions, knowledge, and information learned by an individual, but it is not a static file system that is used only for information retrieval. Abbot (2002) suggested that LTM "is that more permanent store in which information can reside in a dormant state – out of mind and unused – until you fetch it back into consciousness" (p. 1). In order to incorporate new information, LTM must be connected with STM and must be dynamic. There are several categories of LTM, and there are many suggestions as to how memory units are represented. While it seems that it might be sufficient to understand simply that there are individual units and structures that exist in LTM, the specific way or ways that information is stored offers extremely important information. If the knowledge unit is pictorial rather than verbal, for example, it would seem to make sense that images would be more easily and readily stored in memory. If the reverse were true, information should be presented in verbal constructs. This oversimplifies the challenge, but it is this question that is at the core of the controversy over memory storage structures. There are two divisions at issue in the discussion of long-term memory: the types of long-term memory and the type of knowledge unit stored in long-term memory.

**Organizations of long-term memory.** Today cognitive psychologists believe that there are at least two different types of information stored in LTM – episodic and semantic. Each of the memory structures is distinct and serves a different operational function. However, it is evident that some type of very specialized categorization system exists within the human mind. One of the first to make this idea explicit was Bruner (1986, 1990). A basic component of Bruner's theory is that categorization is fundamental to perception, forming concepts, learning, and making decisions.

Tulving (1972) was the first to distinguish between episodic and semantic memory, and all discussions recognize these two distinct types. Most researchers now combine these two in a broader category labeled declarative. Other researchers identified additional organizational types. For example, Abbott (2002) listed declarative and procedural while Pavio (1971, 1986) added imagery to this list. However, Pylyshyn (2002) stated that imagery is not a distinct organizational structure but follows the rules that apply to semantic and episodic memory.

Abbott (2002) defined declarative memory as that which can be talked about or verbalized. It is, then, the sum of stored information that can be readily retrieved and put into words in conscious thought and sharing. As previously stated, declarative memory can be subdivided into both semantic and episodic memories. These two subtypes are radically different although they can each be fairly easily recalled and manipulated. Episodic memory's store is centered on personal experience and specific events. It is entirely circumstantial and it is not generally used for the processing of new information except as a sort of backdrop. "Episodic memories are those which give a subject the sense of remembering the actual situation, or event" (Eliasmith, 2001). This type of memory is somewhat like a personal video of a specific significant day or event, and its parts are not easily disseminated to characteristics or concepts. Semantic memory, in contrast, deals with general, abstract information and can be recalled independently of how it was learned. It is semantic memory that is the central focus of most current study because it houses the concepts, strategies and other structures that are typically used for encoding new information.

Procedural memory can be thought of as "how to" knowledge (Humphreys, Bain, & Pike, 1989). It is the type of long-term memory sometimes associated with information that has reached a state of automaticity, but it is not limited to this. This type of memory is defined in terms of learned skills and the ability to recall instruction-like memory. Paivio (1971, 1986) described imagery as the memory structure for collecting and storing information related to pictures. It captures information much like a photograph and can be extremely useful for context and visual presentation of information.

**Memory storage and representation in stage theory model.** Theories on the representation and storage of memory units provide the foundation for current trends and beliefs in cognitive psychology and must be examined in order for the more recent models to have a solid foundation. It is not that the models to be discussed here have been dismissed or discounted; some aspects of each have been integrated, broadened or narrowed, but each has contributed its own part to cognitive psychology's development. The first alternative model that became widely accepted and discussed was the network model. Collins and his colleagues (ie, Collins &

Loftus, 1975; Collins & Quillan, 1969) laid the groundwork for this model. It assumed that there are nodes or tabs in memory that store information in sections much like a notebook filing system. When stimuli are introduced, this model suggested that the mind references the incoming data to a chapter or node in memory. One advantage of this model is that it accounts for individual differences in its comprehension and filing system. Each person's nodes would be individualized by the experiences and knowledge that person had gained throughout his or her lifetime. Because this proposed a hierarchical system at work in the mind, integration of new information is shown as a process of moving from stimulus to tab to separate pieces filed behind the tab, a very linear progression. This linear progression later became the center of a bit of controversy and led to new models as this network system began to meet with competition.

Smith, Shoben, and Rips (1974) argued against the network model claiming that instead of being organized in a hierarchal system, information is stored as sets of defining characteristics. In other words, associations are made through the comparison of overlapping features between new stimuli and existing characteristics stored in memory, and in doing this, they differentiated two types of features: defining and characteristic. Several major failures have been found in this model, though. First, there is no allowance here for semantic flexibility, and the world and our perception of it are filled with semantic ambiguities that must be mediated. Also, this system would require vast numbers of collections, but it suggested no concrete organizational system for these collections.

The essential difference between these first two types of encoding and storage systems is related to bottom-up and top-down processing. Network models work on the top-down principle; feature comparison models work from the bottom-up. Klatzky (1980) recognized the similarities between these models and essentially tried to end debate about choosing between them. When she coined the term "mental dictionary", she stated simply that their associations to one another represent concepts. In this light, it is of no material consequence which direction, top-down or bottom-up, the information flows and is connected, it simply matters that associations and connections are made. This effectively merged the two ideas saying that feature analysis is simply an enhanced form of the network model.

Anderson and Bower (1973) proposed the next significant model for how knowledge units are stored. Their model was founded on the belief that knowledge is based on verbal units (consisting of subject and verb constructs) rather than perceptions. This prepositional model moved away from categorization and nodes, but it still held that these propositions are organized in a network structure. Another feature that this model shared with the network and feature analysis models was its serial nature. This model, as both of the previous models, is built on the belief that information is encoded in a linear method; in order for new information to be incorporated, it must pass from point A to point B to integration with X. It is the serial nature of these models that differentiates them from the later models of information acquisition. Later theories suggested that information is not incorporated in a linear fashion, but, rather, they are simultaneously processed at different levels and by different memory categories or structures.

### Additional Theories of Information Processing

There are many, more recent theories concerning information processing that differ from the stage theory model, and today, research and study continues to modify existing beliefs in this area of cognitive psychology. Despite the fact that there are commonly accepted pieces, the complete picture of how information is processed continues to change.

**Levels of processing**. One of the first alternatives to the theories discussed above was developed by Craik and Lockhart (1972) and labeled the levels of processing model. Specifically, the levels of processing theory held that memory is not three-staged which separates it immediately from the stage theory model. Craik and Lockhart argued that stimulus information is processed at multiple levels simultaneously (not serially) depending on characteristics, attention, and meaningfulness. New information does not have to enter in any specific order, and it does not have to pass through a prescribed channel. They further contended that the more deeply information is processed, the more that will be remembered (Kearsley, 2001c). This model was a precursor to the development of schema theory, discussed below. In fact, the two are consistent; Rumelhart and McClelland (1986) found that the larger the number of connections to a single idea or concept was associated with the increased likelihood that it was to be remembered.

**Dual coding theory**. As mentioned previously, another theory in the information processing debate is Paivio's work in dual coding (Paivio, 1986; Clark & Paivio, 1991). This theory gave equal significance to both verbal and non-verbal processing and suggested there are two separate systems for processing these types of information. Imagens—mental images—are processed by one system, and logogens—verbal entities, chunks or propositions—are processed by a different system. According to Kearsley (2001b), Paivio believed that:

> Human cognition is unique in that it has become specialized for dealing simultaneously with language and with nonverbal objects and events. Moreover, the language system is peculiar in that it deals directly with linguistic input and output (in the form of speech or writing) while at the

> same time serving a symbolic function with respect to nonverbal objects, events, and behaviors. Any representational theory must accommodate this dual functionality (p. 1).

Further, Paivio suggested there are three separate types of processing and interaction between these two subsystems: representational, referential, and associative. Representational processing is the direct activation of one system or the other; referential is the activation of one sub-system by the other; and, associative is activation within the same sub-system without the interaction of the other.

**Schema theory, parallel distributed processing, and connectionist models**. Rumelhart (1980), working in conjunction with others, developed the schema theory of information processing and memory. He proposed that a schema is a data structure for representing generic concepts stored in memory. There are five key components to this view of memory and processing in relation to schema: 1) it is an organized structure that exists in memory and is the sum of all gained knowledge; 2) it exists at a higher level, or abstraction, than immediate experience; 3) its concepts are linked by propositions (verbal constructs); 4) it is dynamic; and 5) it provides a context or structure for new information (Winn and Snyder, 2001). This model is sometimes called the connectionist model or theory; it emphasizes that information is stored in multiple locations throughout the brain in the form of networks of connections. This model is explicitly similar to the levels of processing theory in that it is founded on the belief in parallel processing of information. Therefore, the connections among pieces of information are key, not the order in which connections are made.

Rumelhart later worked with McClelland and the Parallel Distributed Processing Research Group (McClelland & Rumelhart, 1981, 1986; Rumelhart & McClelland, 1986) to expand his initial work and created the connectionist theories. In this enhanced model, it was still proposed that the units of memory are connections rather than any concrete representation of previous information. The latter model goes further, however, stating that the activation of the connections is the knowledge unit. According to Driscoll (2001), there are many advantages to this model, the most prominent of which are that it accounts for the incremental nature of learning, is dynamic, incorporates goals of learning, and has the potential to explain cognitive development.

### Development of Memory and Information Processing

As previously stated, cognition is the encoding, structuring, storing, retrieving, using, or otherwise learning of knowledge (Neisser, 1967). There are important developmental aspects for each of these activities. According to Flavell et al. (2002), some of the most important contributions to development theory made by the information processing theories are:

1. Brain changes brought about by biological maturation or experience;
2. Increased processing capacity, speed, and efficiency as a result of both maturation and knowledge development;
3. Modifications of connections in a neural network;
4. New emergent concepts arising from repeated self-organization as a result of adapting to the demands of a changing environment; and
5. Increased capacity for problem-solving and metacognition.

These are discussed further using the steps considered in Neisser's definition.

**Encoding**

Encoding occurs during the initial processing of a stimulus or event. Maturation and experience influence this process. In terms of maturation, Dempster (1981) hypothesized that the adult capacity for short-term memory of 3 to 7 digits might be as much as 2 digits lower for children aged 5 and 1 digit lower for children aged 9. As for experience, in a series of well-known studies of expertise, novices remembered new information less well than experts (eg, Chi, 1978; Schneider, Korkel, & Winert, 1989). One of the most important differences between novices and experts is the structure and organization of domain-specific knowledge.

**Structuring and Organizing**

Structuring and organizing information occur as the learner processes and stores information. The learner's ability changes over time as a result of both maturation and experience.

When presented with information they are asked to remember, younger children do not rehearse information in order to remember it. As they get into school, they begin to develop or are taught various strategies. At first these strategies are only used when prompted by someone else, but as the child becomes more competent in their use and uses them more frequently, the child will increasingly use the strategies spontaneously (Flavell et al., 2002).

One of the most important information processing capacities a child develops is the ability to organize information; this is, in turn, influenced by the child's ability to categorize. As is the case with other information-processing capacities, this ability changes with both maturation and experience. One of the basic types of categorization is the grouping of specific events, ideas, people, things, etc. into concepts. Rosch and his colleagues (eg, Mervis & Rosch, 1981; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976) demonstrated two fundamental features to the development of concepts: the ease of identifying similarities of members of the concept and distinguishing differences between members that are not. For example, the development of the concept of animal would be more difficult than developing the concept of dog or cat because it would be easier to identify similarities among dogs or cats and differences between cats and dogs than it would be to identify similarities among all animals or to differentiate all animals from all plants. This has important implications as we design learning activities for children and youth that can help them develop their organizational and storage capacities.

**Storage and Retrieval**

The amount of information that can be stored and retrieved relative to a stimulus or event also changes over time. For example, prior to about age 7 months an infant will not seek an object that has been shown and then removed from view. The infant has encoded the object (such as a rattle) and will reach for it but seems to lose interest as soon as it is no longer in view. At about 7 months, the infant attains what is called "object permanence" and will begin to seek the object if it is removed from view.

A series of studies by Bauer, Mandler, and associates (as cited in Flavell et al., 2002) demonstrated a child's increasing ability to perform simple multiple-act sequences. By age 13 months infants can reproduce three-act sequences; by age 24 months this has increased to five-act sequences; and by age 30 months to eight separate actions. As children gain language skills, their ability to store and recall more complex events increases. This is shown first in autobiographical accounts of daily activities and then to events they may have witnessed or heard about.

Flavell et al. (2002) made four observations about strategy development:

1. Strategy development is not linear. When developing any particular strategy, development will often stall or even regress before it becomes systematically and correctly used.
2. A strategy will continue to develop after it is first demonstrated in its mature form. This continued development may take months or even years.
3. Children show considerable variability in their use of strategies. Children often go back and forth in their use of strategies, changing strategies even after they have been found to work well.
4. Children differ in their abilities to integrate different strategies into a coherent pattern for successful learning. Children must be given

ample opportunity to create successful learning programs that work for them.

## Designing Instruction Incorporating Best Practices for Information Processing

The understanding of how the mind processes and stores information is invaluable to educators as they plan for instruction. If there is little to no understanding of the information processing skills of the students with whom one is working, it would be almost impossible to design instruction that contributes to high levels of learning and achievement. However, attempting to understand the myriad theories of information processing and cognitive development can be overwhelming and contradictory. There are means of structuring instruction, though, that can incorporate the best of all of these ideas, and in order to help students reach higher-level thinking and learning skills, educators must draw from all of these theories.

### Information Processing and Memory

If learning is to occur, educators must ensure that new information is processed in such a way that it can be retained in long-term memory. As previously discussed, in order to achieve this, elaboration and connection must occur between previously learned memory and new information. It has been established that the more deeply information is processed and the more connections that can be made between new information and existing memory structures, the more information will be retained in long-term memory. Therefore, in order to make new material meaningful, instruction must be presented in such a way that students can easily access and connect previous learning and experiences with the new material.

One of the most often cited references to levels of elaboration for instructional purposes is the Taxonomy of the Cognitive Domain developed by Bloom and his colleagues (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956) and recently revised by Anderson and Krathwohl (2000).

Bloom et al. (1965) proposed that educational objectives can be classified in six levels, each more complex than the previous (See Table 2-1). The first level is labeled knowing and simply requires a learner to repeat back what was heard or seen. This involves no elaboration. The second level is labeled comprehension and requires some rudimentary levels of understanding that might involve having the student summarize or paraphrase some information. This requires only modest levels of elaboration. The next two levels, application and analysis, involve more elaboration and show a significant impact on long-term learning when they are used during the learning process. Application involves using the concepts or principles to solve a problem, while analysis involves understanding the relationship among the parts and how they are organized into a whole. The last two levels, synthesis and evaluation, are the most complex and require the highest levels of elaboration. Synthesis involves putting the parts or components together in an original manner, while evaluation is the process of making judgments based on comparison to a standard.

### Table 2-1. Bloom's Taxonomy of the Cognitive Domain

| LEVEL | DEFINITION |
|---|---|
| **Knowledge** | Student recalls or recognizes information, ideas, and principles in the approximate form in which they were learned. |
| **Comprehension** | Student translates, comprehends, or interprets information based on prior learning. |
| **Application** | Student selects, transfers, and uses data and principles to complete a problem or task with a minimum of direction. |
| **Analysis** | Student distinguishes, classifies, and relates the assumptions, hypotheses, evidence, or structure of a statement or question. |
| **Synthesis** | Student originates, integrates, and combines ideas into a product, plan or proposal that is new to him or her. |
| **Evaluation** | Student appraises, assesses, or critiques on a basis of specific standards and criteria. |

Research has confirmed that the first four levels are indeed a hierarchy, while there seems to be a challenge with the ordering of the two highest levels. Anderson and Krathwohl (2000) proposed that the ordering is reversed, with evaluation being less difficult than synthesis, while Huitt (2011b) proposed that they are both at the same level of difficulty though they incorporate different types of processing. There seems to be consensus that both synthesis and evaluation are based on analysis or the ability to compare and contrast parts of a whole and understand the relationship among parts. The type of thinking involved in synthesis is often labeled "creative thinking," while that involved in evaluation is often called "critical thinking." Research confirmed that both are necessary for successful problem solving (Huitt, 1992).

In order to create an environment in which high levels of elaboration are taking place, the educator must build background knowledge and link previously learned material to new. This does not simply mean that he or she should rely on the classes students have had in the past. Connections must also be made thematically between units, lessons, theories, or concepts. One of the writing standards for the Common Core State Standards for grades 9-10 learners, for example, stated students must "draw evidence from literacy or informational texts to support analysis, reflection, and research" (Common Core State Standards Initiative, 2018, p. 46). This is a theme that can be carried through all lessons, units, and literary works, and it can be a thread that helps students connect new ideas and works to ones previously discussed. In addition, this type of thread structure can make the literature more meaningful—at once strengthening and increasing the connections that can be made and the opportunities for elaboration.

If in British Literature students first learn about the qualities the Old English society valued in a hero, could not the same discussion be held when the concept of the hero changes in Middle English literature? And, does this question not require students to draw from information learned in the previous material in order to find an answer? The larger question could certainly then become what does the current literature (popular or academic) tell students about what society today values in its heroes. Even in this simple example, there are tremendous opportunities to allow students to actively integrate new information with old by combining new information with existing knowledge, by building or expanding structures, or by creating new and more diverse structures.

Once the background is established, the new information on the topic can be presented in a variety of ways, but again, in order to ensure understanding and retention, the new material must be connected to concrete examples. For example, if the teacher organized a lesson about the satire in literary terms, it would be absolutely important to follow up the classroom activity by examining an example of a satire and walking students through an evaluation process of the example showing them how and where the example conforms to the characteristics named in the lecture.

When the teacher and learners have examined a satire together, the students could be asked to go through the evaluation process individually or in groups. This allows learners to demonstrate their competencies or deficiencies in a safe environment in which the teacher can guide, refocus, or assist. The important aspect of the activity is that learners are forced to begin to synthesize and evaluate new information based on their previous experiences and any new skills they are developing. To take this lesson full circle, the teacher could ask the learners to create their own satire based on a current social problem, perhaps developing a skit or video in the process.

When a learner creates, either individually or in a group, an original satire at the end of the lesson, the learner has connected with all levels of elaboration in Bloom et al.'s (1956) taxonomy. At the beginning of the learning experience, the class could discuss possible topics as a whole and why certain ideas would or would not be appropriate for satire. In order to bring along learners who might still be having problems, starter sentences or paragraphs could be provided or the teacher could provide more examples of satires for the students to evaluate. Additionally, learners have begun to process information at the formal operational stage (see chapter four for a discussion of Piagetian theory) if they can make the abstract connections required to complete the activities of the lesson.

Another theorist firmly grounded in the information processing approach is Sternberg (1988). Sternberg's theory was focused on cognitive intelligence; he advocated that cognitive development is skills-based and continuous rather than staged and discontinuous as stage theorists proposed. This focus on intelligence separated his ideas from stage theorists because it rejected the idea of incremental stages, but rather hypothesized that development occurs in the same way throughout life differentiated only by the expertise of the learner to process new information. First, and very importantly, Sternberg's model did not differentiate between child and adult learning. Also, he dealt solely with information processing aspects of development and did not incorporate any facets of biological development into his theory. Cognitive development was viewed as a novice to expert progression; as one becomes better at interaction and learning, one is able to learn more and at higher levels. Sternberg proposed that cognitive development occurred as a result of feedback, self-monitoring, and automatization. In this theory, intelligence is comprised of three kinds of information processing components: metacomponents, performance components, and knowledge-acquisition components.

In Sternberg's (1988) model, each of these three components works together to facilitate learning and cognitive development. Metacomponents are executive in nature. They guide the planning and decision making in reference to problem solving situations; they serve to identify the problem and connect it with experiences from the past. There is, however, no action directly related to metacomponents, they simply direct what actions will follow. Performance components are the actions taken in the completion of a problem-solving task. Performance components go beyond metacomponents in that they perform the function also of weighing the merit and/or consequences of actions in comparison to other options rather than simply identifying options. Sternberg's third proposed type of intelligence is the knowledge-acquisition component. This type is characterized by the ability to learn new information in order to solve a potential problem. This type is much more abstract and may or may not be directly related to a current problem-solving task (Driscoll, 2001). This three-leveled view of intelligence comprised the componential aspect of Sternberg's theory, but this is only one of three parts to his larger triarchic theory of intelligence (Kearsley, 2001e).

Sternberg's (1988) theory added the components of feedback to theories of cognitive development; this suggested that an individual's social interaction has some impact on cognitive development. In fact, one of the three parts of his theory was based on the context in which learning takes place; this subpart of the theory "specifies that intelligent behavior is defined by the sociocultural context in which it takes place and involves adaptation to the environment, selection of better environments, and shaping of the present environment" (Kearsley, 2001e). The addition of social context as a factor in cognitive development linked Sternberg to the interactional theories of development of Bruner (1977a, 1986) and Vygotsky (1978). These theories, and others of this type, are premised on the assumption that learning does not occur in a vacuum. Therefore, one must discuss the social and cultural contexts of learning. Driscoll (2001) stated, "Of central importance is viewing education as more than curriculum and instructional strategies. Rather, one must consider the broader context in how culture shapes the mind and provides the toolkit by which individuals construct worlds and their conceptions of themselves and their powers" (p. 221).

### Assessment and Evaluation Concerns

The understanding of how information is stored in memory and the developmental process of learning leads naturally to the issue of how one can best understand a learner's developmental progress and what he or she knows. It is important to address domain-specific knowledge and processing capacities as well as capacities that are non-domain specific.

Dietel, Herman, and Knuth (1991) provided some important guidelines regarding assessment and evaluation. One of the most important points is that data gathered during the assessment process, which in turn, will be used for evaluation purposes, is guided by one's beliefs in regard to learning. As one can surmise from the review of literature on information processing and memory, this can be a very complex task. They reported that "From today's cognitive perspective, meaningful learning is reflective, constructive, and self-regulated. People are not seen as mere recorders of factual information but as creators of their own unique knowledge structures" (p. 3). Therefore, creating accurate assessments for individual learners becomes troublesome.

One might think that a traditional area of strength for the educational system has been the assessment of knowledge and cognitive skills. However, as previously discussed, the cognitive taxonomy of educational objectives developed by Bloom et al. (1956) and revised by Anderson and Krathwohl (2000) showed there are significant differences between lower- and higher-level thinking and knowing. Unfortunately, the testing process now used in the United States overemphasizes lower-level knowing (Stiggins, 2002). The fact that standardized test scores seem to dictate most educational practice identified a direct conflict of interest for ensuring that students are taught and assessed in higher-level cognitive skills. Stiggins argued that the failure to balance classroom assessment of higher-level skills with standardized assessments has drastically hurt the educational system. More recently, "most of the national curriculum standards expect teachers to create active learning environments that stimulate higher-level student thinking" (Freiberg, 2002, p. 56). In view of the demands of modern society, it seems that additional effort must be placed on the assessment of higher-level cognitive skills and information processing (Hummel & Huitt, 1994).

Fortunately for educators, there are many constant themes of information processing regardless of the specific theory to which one subscribes. Almost all ideas related to how information becomes stored in memory agree that the more deeply and meaningfully a learner processes information that is presented in a context-rich manner, the more readily available that information will be. It has been demonstrated that when new information is presented within a context of knowledge that a learner possesses, he or she has background knowledge with which new information can be compared and categorized. This categorization is also a critical piece of information processing at high levels.

These theories all work under the assumption that new information can most effectively be learned if the material can be matched to memory structures already in place (Winn and Snyder, 2001, p. 3). Most theories hold that the mind contains some type of framework into which new information is placed. This structure is multi-leveled and has varying degrees of specificity. New information can be matched with, compared to, joined with, or modified to fit with existing structures. This in-place structural system allows for differing levels of complexity of information processing. The formation of and continual building of these structures, then, is critical in order for learners to process information in various ways and at higher levels. Again, though, the question becomes how to assess this development.

What, then, should cognitive assessments look like? If one argues that current methods are inappropriate, why are they so? What should these assessments do differently to accommodate the best theories of development and help move students to higher-level thinking and information processing?

Stiggins (2002) said, "Clearly, over the decades, we have believed that by checking achievement status and reporting the results to the public we can apply the pressure needed to intensify – and thus speed – school improvement" (p. 3). This has not occurred. He argued, though, that there are ways that assessment can directly improve schools. "If assessments of learning provide evidence of achievement for public reporting, then assessments for learning serve to help students learn more. The crucial distinction is between assessment to determine the status of learning and assessment to promote greater learning" (p. 4). The factor that he views as most important for this more formative view of assessment is to involve students in the process and help them to be accountable for their learning.

## Summary and Conclusions

In summary, there are many different theories of information processing that focus on different aspects of perceiving, remembering, and reasoning. One of the most important agreements is that elaboration is a key to permanently storing information in a way that facilitates its quick retrieval when it is needed. Bloom et al. (1956) and Anderson and Krathwohl (2000) provided some excellent suggestions as to how we can encourage increased elaboration among our students. However, as advocated by Hummel and Huitt (1994), if students are not required to demonstrate the results of elaboration on meaningful tasks such as examinations or projects, they are not likely to adequately develop the skills required for higher-level thinking. It is, therefore, imperative that educators and parents require the development and use of these skills as a normal process of students' lives. If we do that, the amounts and types of student knowledge will increase dramatically and students will be better prepared for life as adults in this rapidly changing, global, digital sociocultural milieu in which humanity finds itself (Huitt, Chapter 12, this volume).