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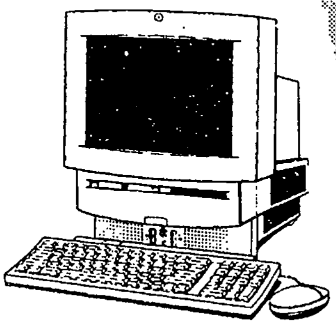
ABSTRACT

The cognitive revolution began in the 1950s as researchers began to move away from the study of knowledge acquisition and behaviorism to the study of information and the way it is processed. Four factors are discussed in chapter 1 as contributing to the increase in popularity of the "cognitive revolution" (increasing enthusiasm for the cognitive approach). This historical perspective on cognitive psychology includes an examination of cognition as a constructive process, structuralism, functionalism, the association approach to memory, Hermann Ebbinghaus, and measuring retention. Some basic characteristics of memory are also explained. Chapter 2 examines the processing of information. A discussion of the structure of memory includes sensory register, short-term ("working") memory, and long-term memory. A section on mnemonics outlines strategies such as the methods of places, association, and keyword. The nature of forgetting and memory interference are also discussed. Chapter 3 examines representations of knowledge, including network models of long-term memory; procedural and metacognitive knowledge; the conditions of learning; concepts; prototypes; schemata; scripts; and goals and plans. Graphic representations of knowledge are explored in chapter 4. An introduction to concept mapping is offered, and hypermedia and hypertext are examined in depth. Chapter 5 discusses problem solving in terms of behaviorism, Gestaltism, information processing, solution paths. Methods of problem solving are highlighted: random search strategies, heuristic search strategies, proximity search, means-end analysis, pattern matching, and domain-specific problem solving. Artificial intelligence and expert systems are covered in chapter 6. Chapter 7 explores the history of education and educational media. (Contains 153 references.) (MAS)

The COGNITIVE REVOLUTION and the COMPUTER



Version 2

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1995

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Chapter I

The Cognitive Revolution

A characteristic of our times is the staggering advances made by the physical sciences as well as of recent breakthoughs in the biological and neural sciences. As of now, two major mysteries of ancient times—the nature of physical matter and the nature of living matter—are well on their way to becoming unravelled. At the same time, a third mystery continues to elude us—the enigma of the human mind. Confounding the study of the mind is the difficulty of separating the *what* we think from what we think *about*. The cognitive revolution began during the 1950's as researchers began to move away from the study of *knowledge* to the study of *information* and the way it is processed.

A major theme of cognitive science is the notion that information can be thought of in a way entirely divorced from specific content or subjectmatter. As researchers began to analyze how the computer, for example, handles whatever information is put into it, it became obvious that humans, too, harbor an information processing system. By the 1970's, psychologists, educators, and instructional designers alike, began to abandon mainstream, behaviorist psychology.

The Need to Understand How Humans Think

The core of behaviorism—the reinforcement principle—did not adequately explain the complexity of thinking, memory, problem solving, and decision-making. Since behaviorism, through reinforcement theory, explains how behavior is repeated, or strengthened in a variety of settings for both animals and humans, it is really a theory of *motivation*, rather than a theory of knowledge acquisition. The cognitive revolution went beyond the why of behavior to the thought processes upon which behavior is based. Cognitive psychology focuses on the acquisition, storage, retrieval, and uses of knowledge. While behaviorist theory explains how learning is acquired, cognitive theory explains how learning is processed after it has been acquired. If we use cognition every time we acquire some information or learn, then cognition includes a wide range of mental processes, such as: attention, perception, memory, imagery, problem-solving, and decision-making (Matlin, 1989).

Cognition, according to the Penquin dictionary, is 'the faculty of knowing and perceiving.' Cognitive instruction refers to "any effort on the part of the teacher or the instructional system to help students process information in meaningful ways and become independent, competent thinkers" (Jones, 1986, p. 7). However, cognitive psychology is concerned not just with learning something approximately or to some extent, but learning it *well*. Our interest is not solely with what makes individuals *intelligent*, but what makes them *competent* (Glaser, 1990).

Four Factors

The increasing enthusiasm for the cognitive approach has sometimes been called the "cognitive revolution." Four factors contributed to the dramatic increase in popularity of cognitive revolution:

- **Behaviorism did not go far enough in describing the nature of complex human behavior. While behaviorism was very good at explaining simple behaviors such as increasing reflex actions in animals, it was not achieving any results in the higher mental capacities characteristic of humans. There seems to be a fundamental difference in how animals and humans learn.**

- **Linguists, such as Noam Chomsky (1957), rejected the behaviorist explanation for language acquisition and presented strong evidence for an inborn ability to master language. Every normal 2- to 3-year old acquires the basic structure of its native language with little formal training and only sporadic reinforcement.**

- **Jean Piaget, a Swiss psychologist, had developed a comprehensive model of cognitive growth that emphasized how children come to understand concepts such as object permanence, and which demonstrated that children advance through developmental levels as a function of age, rather than any form of reinforcement. His theory of development has been demonstrated in many studies and in different cultures.**

- **The information processing model emerged from many sources, such as the communication sciences and computer science. It has proved to be a useful and productive model of the human learning process (Matlin, 1989).**

Historical Perspective

Cognitive psychology, as we know it today, has existed in some form since the Greeks, who speculated on the nature of sense impressions and knowledge. When we look out of the window at a tree, light rays from that object bounce off the retinas of our eyes, but an *image* of that tree stays in the mind in some form. Furthermore, the light rays seem to activate a process of *constructing*, or *interpreting* the tree, thereby creating a visual perception that makes the experience memorable. According to Plato (427-347 B.C.), the tree we see in our mind, is in fact a construction, or copy of an idea, or hypothetical tree. An actual tree exists innately in human consciousness. Plato believed that all reality exists in a spirit world or another dimension. We inhabited this other dimension before birth, and we dimly remember the objects that we encountered there. Thus, when we see a "tree," we are able to identify it as a copy of the idea of a perfect, or higher order tree.

Cognition as a Constructive Process

According to Plato, all knowledge is innate. Day-to-day, visual experiences activate the store of knowledge. Essentially, we *remember* the knowledge. The realm of the absolute forms was considered by Plato to be of a higher value and reality than the world of physical copies that we encounter in the mundane world. As an example, Plato proposed that a geometric figure is "perfect." It is possible for a human being to "think" of a perfect circle, but it is impossible to actually construct or draw a mathematically perfect one.

Philosophers since Plato have rejected this belief in innate *ideas*, but believe that the human mind is equipped with an innate *interpretative* mechanism. For example, humans have an innate sense of *logic*. The simple sentence—a subject acting on a predicate—is a very basic form of logic which is innately understood. Things act on other things, or objects exist in relationship to something else. It is a "given"; we are unable to conceive of a language system that doesn't have it. The ability to construct meaningful sentences with is a universal ability no matter what the language is.

Structuralism

The first formal study of cognition emerged from the study of sensory stimuli and their subjective impact on the individual. Wilhelm Wundt (1832-1920) is generally credited to be the first to study experimentally the *experience* of sense impressions

and knowledge. Wundt's psychology, called **structuralism**, had three major aims: (1) to identify the basic cognitive processes; (2) to determine how knowledge and thought processes are combined and what laws govern these processes; and (3) to determine the relationship of cognitive to physiological processes (Titchener, 1909).

Wundt developed the method of introspection to study cognition. Introspection was a process of self-report, in that subjects described their thoughts as the words were presented to them. It was found that while subjects were very willing to report their thoughts, their actual responses were not very accurate.

Functionalism

In contrast to structuralism, which was very theoretical, **functionalism** developed from a need for a learning theory to generate solutions to everyday problems. William James, an American psychologist, in his Principles of Psy*chology*, took a decidedly pragmatic look at human thought and behavior. He suggested that psychological mechanisms exist because they have "survival value"—they are useful and help individuals to survive and carry out important activities of living. He assumed that *purpose* was the mark of human behavior. The objectives of functionalism were to determine (1) how mental activity functions, (2) what mental activities accomplish, and (3) why it takes place (Keller, 1937, p. 77).

Another philosopher-psychologist, John Dewey (1859-1952), went even further. He emphasized that psychological enquiry should contribute to an enlightened citizenry skillful in problem solving and practical matters. Dewey became influential in American education as his theories helped promote a practical-based curriculum.

Functionalists focused on such subjects as the scientific method of inquiry and short- and long-term memory processes. Research in functionalism utilized the introspective methods of data-gathering characteristic of structuralists, but broadened to more objective methods, such as observations and statistical surveys. A centerpiece of early research was **memory**, because so much of the human personality is the sum total of what is retained from the past.

The Associationist Approach to Memory

When you know that you will have to recall certain information at a future time—such as tasks you must tend to on Friday or items you will need at the grocery store—what can you do do make sure you will remember? Someone once said that everything that we are depends on what we remember about ourselves—our memories. "Memory is a record of past events," sounds like a reasonable definition. The rings of a tree provide a record of rainfall and other weather conditions in past years. The dirt on the soles of your shoes provides a record of where you were this morning. These are *records* of past events, but none is a *memory* because they do not describe the circumstances that are associated with those events.

Hermann Ebbinghaus

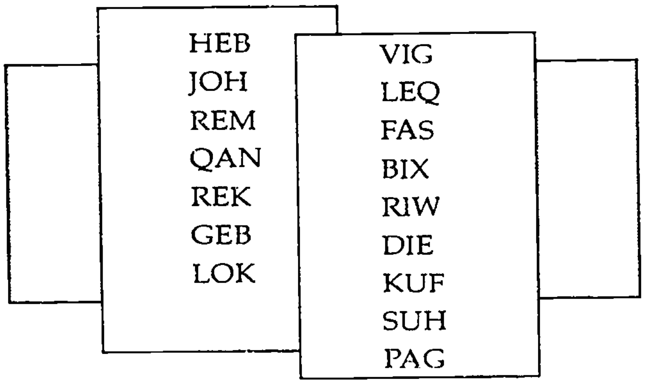
Since the time of John Locke, David Hume, David Hartley, and other British philosophers of the 1600s and 1700s, *association* (the linking of sensations or ideas) has been regarded as central to all thought processes. By the 1800s, associationism had become the dominant view of memory and related processes.

According to associationism in its original form, all experiences consists of simple sensations or other psychological "elements." Similarity or contiguity in time and space links those simple elements together—"associates" them—into more complex structures, much as chemical bonds associate atoms into compounds.

Such was the theoretical environment in which the German psychologist Hermann Ebbinghaus (1859-1909) undertook his study of memory. Like many other psychologists of his time, Ebbinghhaus began by interpreting memory in terms of association. Unlike the others, however, he devised a way of studying memory experimentally. Previously, when investigators asked people to describe their memories, they had no way of determining whether the descriptions were accurate.

Ebbinghaus simply taught a person something completely new and then tested the person's memory of it. This procedure enabled him to control certain variables (such as amount of practice and delay before testing) and to determine whether the person's memories were accurate.

To make sure that the material to be memorized would be unfamiliar to his subjects, Ebbinghaus invented the nonsense syllable, a meaningless three-letter combination such as FOH or TAF. He wrote out 2,300 such syllables and arranged them in a random list. (See Figure 1). He wanted to measure how rapidly people could memorize such lists and how long they could remember them. Since he had little money and no access to introductory psychology students to utilize for research, he experimented on himself. Over a period of about 6 years he memorized nearly 10,000 lists of nonsense syllables.



HEB
JOH
REM
QAN
REK
GEB
LOK

VIG
LEQ
FAS
BIX
RIW
DIE
KUF
SUH
PAG

Figure 1

One of Ebbinghaus's first discoveries was that it takes longer to memorize a long list than it takes to memorize a short one. This may be obvious to us, but Ebbinghaus was able to measure, systematically, *how much* longer it takes to memorize longer lists. Figure (2) gives the results. He was able to memorize a list of up to seven syllablesisingle reading, but each additional syllable increased the number of repetitions required to recall the list.

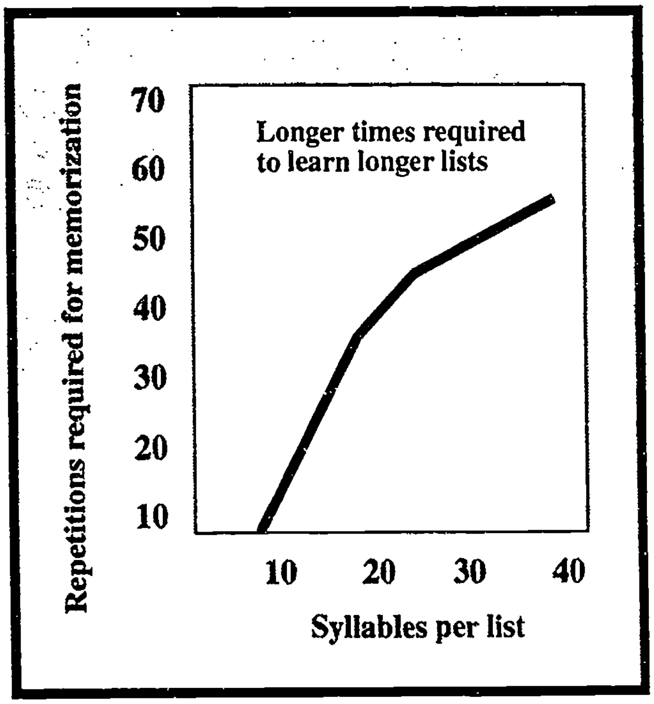


Figure 2

Measuring Retention

From the pioneer work of Ebbinghaus, research methodology on memory developed into three major designs:

- SERIAL LEARNING: The subject learns to recite a list of items (syllables, words, digits).

- FREE-RECALL LEARNING: The subject tries to recite a list of items in any order he or she chooses, at any speed.

- PAIRED-ASSOCIATE LEARNING: The subject learns a pair of discrete associations (pairs of syllables or words). The responses may be made by pressing buttons on a keyboard, or by recalling the units themselves, such as foreign-language words. (See Figure 3)

Memory is measured by four methods: (1) **recall**, (2) **cued recall**, (3) **recognition**, and (4) **savings**, or **relearning method.**

The simplest way to measure your memory is by **recall**. To recall something is to produce it. For example, I might present you with a list of U.S. Presidents. Later, I might ask you to recall as many of them as you can. Essay examinations require much recall of facts and principles.

Cued recall may tease out some presidents that you can't quite remember. to help you recall, you are shown photos of all the presidents, which may result in total recall.

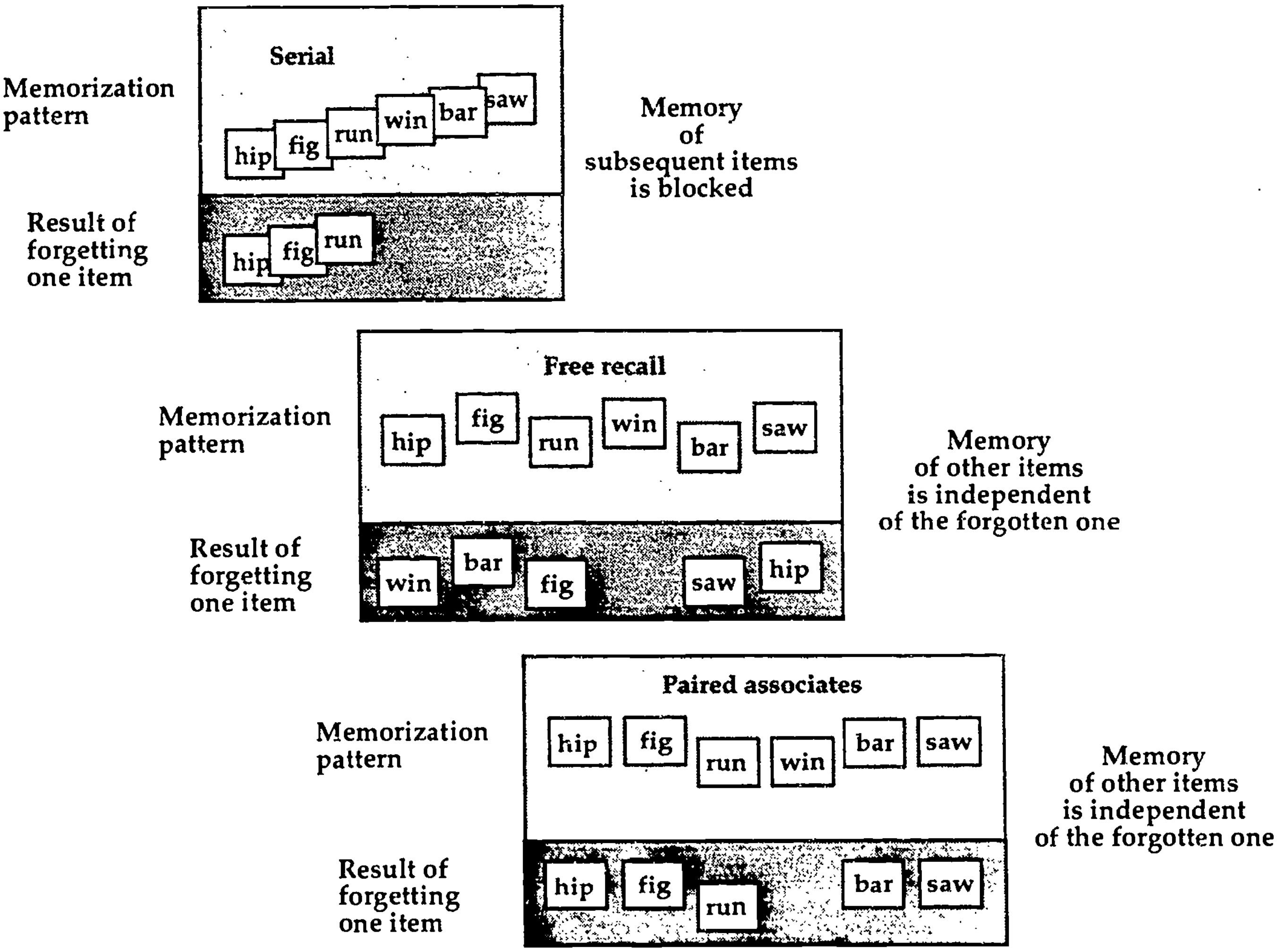


Figure 3

In **recognition**, a third method of measuring memory, a person is asked to choose the correct response from an array of items. We often are able to recognize a memory that is too faint to be brought to mind by recall, or cued recall. Recognition is an easily quantifiable method. Retention can be measured by how much of an original text or a concept is recognized after a given period of time—the conventional method used in schools. If a 4th grade class recognizes correctly an average of 8 out of 10 names of U.S. presidents at the end of May, but upon retesting in early September recognizes an average of 4 correct out of 10, their recognition rate is 50%. The recognition method is used in educational settings in the form of multiple-choice tests.

The **savings**, or **relearning** method was developed by Ebbinghaus. How much you have learned is measured by how much you "save." The less time needed to achieve the previous level of learning, the greater the amount of learning has incurred. If a soldier during summer reserve training is able to achieve the breaking down and assembling of an M-16 rifle in 5 training sessions, compared to the 10 trials that it required during earlier, basic training, the soldier has "saved" 50% of what he or she has learned. Time is a basic variable used in the military to insure that learning has occurred.

Some Basic Characteristics of Memory

Ebbinghaus and others discovered several factors that influence how we memorize information. Length of the list of information to be recalled is one factor. Early in the school years, children become quite aware that they can learn a short list quite a lot faster than a longer one.

A second factor that affects memory is the order in which the items appear on a list, or presented to the listener—their serial order. According to the **serial-order-effect**, the names of the persons introduced to you at the beginning and at the end of the party are likely to be more accurately remembered than all the others you met. The first items in a list are easy to remember because we can rehearse them without any interference from other items, or people at the party. When you meet others, their names get "lost in the shuffle," but the last person will stand out because he or she is the last one. A third factor is **distinctiveness**, the quality of being different from the others. When you are introduced to John, Sue, Mary, Bob, Mohammad, and Fred, it is quite likely that Mohammad will stand out in your memory.

A fourth factor that affects ease of memorization is **meaningfulness**, the ability of an item, or individual, to fit into a known pattern of information. If one hears a list of U.S. Presidents with Abraham Lincoln somewhere near the middle, his name is likely to stand out because it is so meaningful—especially to a Lincoln fan. Individuals who know a lot about baseball will recall much more about a particular game than one who saw only a lot of people running around a baseball field chasing a ball. Thus, meaningfulness is largely a function of what the viewer brings into the situation in terms of background knowledge, experience, and interest.

Chapter II

The Processing of Information

When scientists wish to understand complex processes, they often construct a theoretical *model* of what they are studying. Constructing a workable and accurate model of the DNA molecule, for example, was a major step for researchers in biology and genetics toward understanding the transmission of genetic information. Similarly, cognitive psychologists have constructed models of cognitive processes. Many of these models picture the human being as an information-processing system. The concept originated in experimental psychology and computer technology (Bower & Hilgard, 1981). The present focus of information processing models is on the cognitive mechanisms of sensory register, short-term, and long-term memory (Atkinson & Shiffrin, 1971; DeCorte, 1980). (see Figure 1)

The Information Processing Model

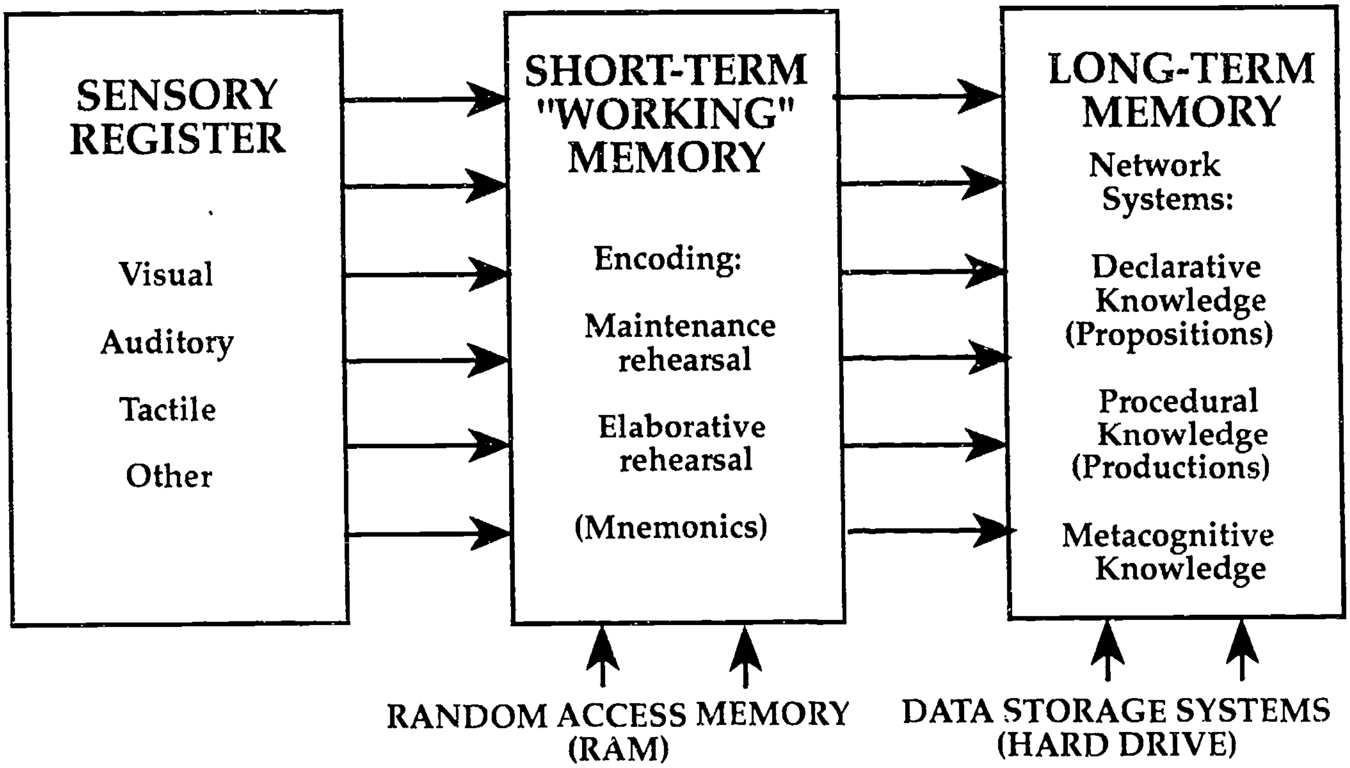


Figure 1

What do we mean by "information processing"? Well, you are processing information right now. You are *attending* to these printed words. Visual stimuli in the form of words are received by your *sensory* register for a fleeting interval and then move into the area of conscious thinking processes—*short-term memory*. Now, while you are processing this immortal prose, you are probably tuning out external sounds of the room ventilator, outside traffic, or even conversation by others around you. These have been *filtered out* by your mechanism of attention, which allows you to concentrate almost completely on one sensory input. In between this you may be thinking of what you will have for lunch or what time you need to get to class. When you later recall the information (for example, from this paragraph), you may find that some ideas are forgotten. You might also remember information which didn't actually occur but was constructed by existing information in your mind. All of this is information processing.

THE STRUCTURE OF MEMORY

A. Sensory Register

As shown in Figure 1, the flow of information begins with input from the environment, such as the visual perception of words. This visual information enters an area called a **sensory register.** Information in the sensory register is stored briefly—usually for only 1 to 3 seconds. Once it is in sensory register, information will be lost unless it is attended to. One aspect of the sensory memory is that it is extremely expansive. Virtually nothing escapes it. This is what often leads to the "double take." You may be looking around at a large scene and suddenly be caught by a familiar object. The way we process information that enters our sensory register is called attention. **Attention** refers to a conscious effort to focus on information from some particular aspect of the environment (Travers, 1982, p. 49), and then to actively work on this information. But how does attention work? Why are some events in the environment attended to while others are not? How can the human consciousness sort through the vast amount of data to which it is exposed? There are two explanations for the attention process: the **bottleneck theory,** and the theory of **Ulrich Neisser.**

Bottleneck Theory

Humans are quite limited in the amount of information they can process at any given time. A common metaphor for this limited attention is the idea of a bottleneck: a narrow opening that restricts the flow from one area to another. According to this explanation, the sensory register is a bottleneck that not only restricts the quantity of information to which we can pay attention, but if one message is currently flowing through the bottleneck, then other messages must be left behind. In one experiment, subjects were asked to listen to two phone conversations—one in each ear. However, they were asked to focus, or attend to only one conversation. It was found that subjects could not remember specific content of the unattended conversation. However, they could recall broad, sensory information, such as if the speaker's voice was male or female. Only large sensory information but not specific content can be recognized if it is not attended to.

Neisser's Theory

Ulrich Neisser (1976), an early pioneer in cognitive science, believes that the human being has a very large capacity to receive information through the sensory register. In contrast to the limited capacity proposed by the bottleneck theory, Neisser states "there is no physiologically or mathematically established limit on how much information we can pick up at once" (p. 99).

Neisser believes that the concept of a limited capacity for information intake is not consistent with what we now know about the active, developing structures in the human brain. The brain contains millions of neurons, which are related to each other in extremely subtle ways. According to Neisser, since there are probably no limits on the size of long-term memory capacity, there should be no fixed capacity to the amount of information that normal adults can gather in at one time. Theoretically, this may be true, but for most of us, the amount of information we can take in at any given time is limited.

Imagine yourself at a crowded, noisy party. You are standing with one group of people, surrounded by other people. To which conversation will you listen? Despite all the noise, you can decide on only one of the many conversations you want to tune in on. You could eavesdrop on the conversation behind you, or on the one to the right or left. But any conversation you listen to causes the loss of the others. This, then, is the selectivity of attention. It is possible to stand in the room and select which of several conversations to follow, but it is not possible to take part in two or more different conversations simultaneously. However, several conversations can be monitored by following a few words from each and perhaps noting who is there. But if the conversations are at all serious, the sense of each gets lost when you try to take in too much. It is possible to be selective in extracting sense out of all the noise of the party, but there is a limit to the ability to understand different conversations simultaneously

B. Short-term ("Working") Memory

According to the information-processing model, most of our minute-to-minute, conscious mental activities takes place in **short-term,** or **working,** memory (Kintsch *et al*, 1984; Kolodrier, 1984). Our short-term memory is the place where stimuli—information—is analyzed, transformed, and made ready for placement in long-term memory (Reynolds & Flagg, 1983). Here the information is not a complete image of the events that occur at the sensory level, but the immediate *interpretation* of those events.

If a sentence has been spoken, you do not so much hear the sounds that made up the sentence as you learn the words. There is a distinct difference here between interpreting an image or sound in the environment and interpreting the meaning of those stimuli.

By definition, short-term memories fade rapidly. Information we take in every day passes through short term memory where it is either rehearsed or forgotten. Every day, we enter many facts into our short-term memory—an address, a telephone number, a list of items from the grocery store—that we use briefly and then forget. In a classic study of short-term memory, Peterson and Peterson (1959) asked subjects to remember 3 sets of nonsense syllables. After the subjects heard the syllables, they waited and then were asked to recite the letters. Peterson and Peterson developed a process by which subjects were prevented from rehearsing. They were asked to count backward by threes—a difficult task that involves some concentration. When they were asked to count backwards immediately after hearing the three letters, almost all of them failed to recall the letters. In other words, if the subjects are prevented from rehearsing information that had entered the short-term memory, this information generally faded away within 20 seconds or so. Counting backwards interfered with the subjects' rehearsal of the syllables, making it more difficult to recall them.

Only by conscious effort can information be maintained in short-term memory and eventually incorporated into long-term memory. By repeating the material over and over again, it can be maintained in short-term memory for an extended time. Consider a phone number: Phone numbers were developed with seven letters because this is the amount of information whichg may be maintained through researsal. However, once the number has been dialed su ccessfully, it is usually forgotten.

Three theories describe how information is processed in short-term memory: (1) **depot theory**, (2) **consciousness theory**, and (3) **perceptual theory**.

Depot Theory

According to this metaphor, short-term memory is the place where information arrives and then piles up in a rather disorganized fashion. This process is *volatile*, because the information is in a state of change, or decay. As an example, remember your last camping trip? Everything was packed meticulously for the journey out, but when you returned home you piled all your gear in the middle of the basement floor. Later, when you wanted something, it was buried in the jumble of equipment. Had you carefully sorted the items, placed them in their proper places—in short, *encoded* that content—every item would be easily retrievable later, when you needed it. Similarly, when we hear a lecture and take notes, a good encoding procedure would be to rewrite those notes, restate the information, add further elaboration to the data, etc. This process organizes what you hear and makes information maximally retrievable.

Consciousness Theory

This explanation is based on the common sense knowledge that short-term memory is really our conscious state of mind. As you read this you are quite aware of what you are doing. Consciousness can range from low-level awareness (thinking of these words while thinking other thoughts as well), to intense concentration, or heightened awareness. Impending danger can heighten our consciousness dramatically, and thus there is likely to be a high degree of encoding. On the day you were married, the few moments before you said "I do" were moments of extreme awareness. Retention of that moment is likely to be quite permanent.

Perceptual Theory

This has elements of both previous theories. To "perceive" an event, or a place, is to attach some meaning or significance to it. To rearrange that pile of camping equipment is to impose order and personal meaning to it, and in so doing we are likely to be psychologically close to it. To read these words may have *some* significance to you now, but to hear your instructor announce that you will be tested on this chapter very soon and your performance weighted heavily in the final course grade is to alter your perception of these words. According to the perceptual theory of short-term memory, it is this process of attaching meaning, or significance, whether positive or negative, that constitutes the nature of encoding.

C. Long-term Memory

The Process of Encoding

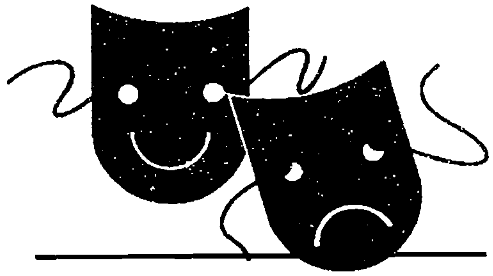
Whether short-term memory is a depot, a state of consciousness, or a perceptual process, it is what happens while information is there that determines if it will go into long-term memory, be retrievable and, therefore, truly memorized. Encoding is the process of making information meaningful so that it may be related to the complex structure of information in long-term memory. The most prominent theory of encoding divides the process roughly into maintenance rehearsal and elaborative rehearsal.

Maintenance (Type I) Rehearsal

Consider the case of Suzie, who has just gotten the part of Adelaide in her high school production of "Guys and Dolls." She must spend many hours committing her lines to memory by *maintenance rehearsal* (called Type I researsal), the direct re-cycling of information to keep it active in short-term memory. Her first reading of the play will familiarize her with the general actions and events, but by the time she gets home from school she may have little remembrance of specific lines. If it is a brief speaking part, all that may be required is rote learning—repeating the lines until they are memorized. But if the passage is lengthy, Suzie will have to develop an *elaborative* strategy for committing it to memory.

Elaborative (Type II) Rehearsal

Suzie has many of her lines "down pat," but she will have to speak and sing them clearly and forcefully in front of a live audience and under glaring lights. A convincing performance under those conditions will require considerable *elaborative rehearsal* (called Type II rehearsal). This involves a deeper and more meaningful understanding of the plot and lines of the musical play. She needs to think about the characters the words depict, their relationships to other characters in the play, and the cues of dialogue and action which precede her lines. In short, she has to immerse herself in the context of the play and the character of Adelaide, whom she is playing. This will be a much more difficult and time-consuming process than maintenance rehearsal, but it could result in Suzie's recall of some of Adelaide's major speeches for the rest of her life, or at least for the run of the play.



Research suggests that elaborative rehearsal is far superior to maintenance rehearsal for long-term recall, but of course it requires a considerable amount of cognitive effort (Swing & Peterson, 1988; Bjork, 1975; Craik, 1979; Elmes & Bjork, 1975). Craik (1979) suggests that maintenance and elaborative rehearsal are opposite ends of a continuum. At one extreme of the continuum is the minimal processing needed for rote memory, where the content to be learned is not changed any and is minimally related to other information. Elaborative rehearsal is intended to result in truly meaningful understanding and long-term retention. Different types of rehearsal are appropriate for different tasks, and different methods of rehearsal are teachable (Palmere *et al*, 1983; Phifer *et al*, 1983). A short-order cook, for example, needs to retain a specific food order for a short time only. If he couldn't "forget" all those orders by the end of the day, the result could be a serious case of information overload. By contrast, learning the steps of long division must be encoded by a process of elaborative rehearsal. Long division is not only a necessary tool by itself, but the prerequisite for more complex mathematics.

Studies by Glover and his associates have repeatedly shown that a combination of effort and elaborations of the materials are good predictors of how well students encode and later retrieve text material (Benton *et al*, 1983; Glover *et al*, 1982). Almost all of the research on short-term memory processes supports the conclusion that students will probably learn more if we can find ways of helping them become better at encoding and if they are encouraged to deal with new information in terms of meaning and understanding. Research and common sense also tell us that having students simply repeat material, or spend more time just reading and re-reading, are probably not the most efficient ways to ensure that they will learn and remember the content. Our instructional goals would probably be better met if we were able to provide strategies that helped to ensure that what they do process, they process deeply (Resnick, 1987).

The phrase **depth of processing** is often used to describe the way information is encoded into the memory system. The basic assumption underlying depth of processing is that what people remember depends, to a great extent, on the methods with which they encode information during learning (Anderson, 1980). Encoding can take place at any one of several levels in the processing system, and that the deeper the level of processing, the better the chance that the information will be remembered (Craik & Lockhart, 1972).

Methods of Encoding

"If you throw a handful of marbles on the floor," wrote the Scottish metaphysician Sir William Hamilton, "you will find it difficult to view at once more than six or seven at most without confusion." With this pronouncement, according to Miller (1956), Hamilton became the first person to investigate how much can be mentally grasped at a given time. Subsequent research did, in fact, confirm Hamilton's observation: six or seven is close to the limit on the number of units we are able to perceive accurately without counting. Beyond six or seven, errors begin to occur. How is it possible then to encode larger examples of information when short-term memory can only hold 6 or 7 items?

As Miller (1956) pointed out, in terms of what we can "keep in mind" we seem to be in a position analogous to carrying a purse that will hold no more than seven coins, whether they are pennies or dollars. Obviously, we can carry far more in our memory if we stock it with information-rich "dollars" than with "pennies," such as single letters or digits. The more information that can be combined or organized, the greater the amount of information we can hold in memory, even though the number of units remains constant. As mentioned, short-term memory has the capability to hold about 5 to 7 items. With the chunking method, more items are made to fit into these 5-7 slots and therefore reach long-term memory.

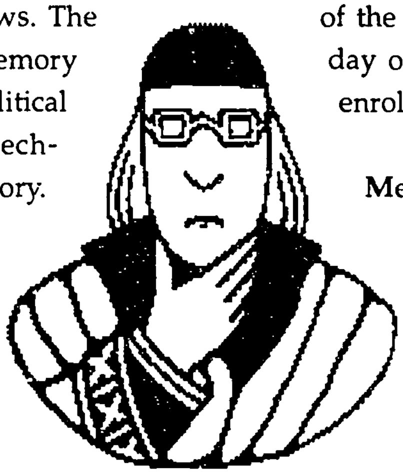
Chunking

In a landmark paper published in 1956, entitled "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information," Miller not only presented considerable evidence regarding the limits of our active memory, but also introduced a unit against which this limit could be calibrated—the chunk. A *chunk* is any stimulus (e.g., letter, number, word, phrase) that has become unitized through previous experience (Simon, 1986). Thus, the sequence of letters X-J-M presented consists of three chunks of information, as does the word sequence "cat-dog-fish" or the number sequence "7-1-9." Miller (1956) cited the example of a beginning radio operator learning the Morse code. At first he, or she, hears each dot and dash as a series of separate sounds. Then the operator begins to organize groups of sounds into letters, so the letters are the recorded chunks. Subsequently, the operator organizes groups of letters into words. As the chunks get larger, from dots and dashes, to letters, and then to words, the operator can remember a correspondingly longer message.

Another way to chunk information is to break the task into separate parts. Then break each part into additional parts. Also, practice certain skills until they become automatic (i.e., they can be done with little conscious effort, thus freeing short-term memory for concentration on other aspects of the larger task).

Mnemonics: The Arts of Memory

The subject of memory has a long and interesting lineage (Rachel, 1988). In the centuries before the development of the printing press, the arts of memory were the primary means for preserving cultural traditions and community laws. The story-teller depended on a keen memory aided by rhyme and meter. In the political arena, a knowledge of memory techniques was essential for formal oratory. Interestingly, the memory arts were associated with occultism, with memory artists regarded as "stage performers" (Paivo, 1971). However, as a result of printing and the emergence of mass literacy, the importance of memory as a medium for communication has declined.



The term mnemonics refers to the use of learning devices and strategies to aid in remembering. Some mnemonic tricks are familiar to almost everyone, such as rhymes used to define the rules of spelling ("i before e except after c"), or internal memory aids that utilize imagery (e.g., mentally rehearsing the items one intends to buy). There has been a definite increase in the use of mnemonics, a memory procedure that has been around for a long time (Levin, 1980). Bower and Clark (1969) observed that serial recall could be improved when a story mnemonic was employed. Bower and Winenz (1970) demonstrated the superiority of imagery mnemonics in paired-associate learning.

Three main mnemonic methods are (1) places, (2) **associations**, and (3) **keywords**.

Method of Places

This was a trick of ancient orators: to visualize and place, in exact order, the locations or places that create a set of "memory snapshots." When it is necessary to recall these items, it will be relatively easy to "walk" down the street or through the woods and visualize the items to be remembered. The recall of information, especially objects, is very much a matter of the *context* or environment in which the encounter occurred. Teachers can often recall personal characteristics of former students by being reminded of the semester, room location, and time of day of the class in which the student was enrolled.

Method of Association

Acronym is the combination of the first letters in a list of information. For example, HOMES, the first letter of the five Great Lakes, is a popular acronym. Another useful one is ROY G. BIV—red/orange/yellow/green/blue/indigo/violet—the colors of the spectrum.

Acrostic is the combination of words to make a sentence. Perhaps the most famous is Every Good Boy Does Fine for the lines of the music staff (E, G, B. D. F). Remembering the order of planets from the sun can be aided by the acrostic: Men Very Easily Make Jugs Serve Useful New Purposes, for Mercury/Venus/Earth/Mars/Jupiter/Saturn/Uranus/Neptune/Pluto.This mnemonic is particulary useful while learning rules, laws, and principlesd.

Method of Keyword

One of the most extensively used mnemonic devices is the **keyword** or link method, originally developed for teaching foreign language vocabulary but later applied to many other areas (Atkinson, 1975; Atkinson & Raugh, 1975). For example, in Spanish vocabulary "trigo" means "wheat." The keyword method involves two stages: first, a verbal *acoustic link* must be established, in which the foreign language word is changed into an easily pronounced English "keyword." This keyword must sound like part of the foreign word; for example, "trigo" can be converted into "tree." Second, an *imagery link* must be formed between the keyword and the corresponding English word. For example, the learner could picture a tree that grows stalks instead of leaves. As another example in English vocabulary, "sear" means "to burn." "Sear" sounds like "sear-loin steak." One can imagine a burned Sirloin steak to remember what "sear" means.

The keyword method requires practice for it to be effective. The information to be remembered by means of a keyword must be very important in itself, or as a link to other concepts or principles in order to justify the time and effort required to construct them. The most important aspect to all three of the mnemonic devices is visualization. The act of visualizing objects is extremely helpful in the memorization process. If vocabulary is visualized as physical objects, it is more likely to be remembered. Another interesting phenomenon characteristic of mnemonics is that a memory aid does not necessarily have to make sense. In fact, the more bizarre they it is, the better. For example, one could a giant steak walking down the road, or a large man with various objects hanging off him. Most likely if the objects are very untypical, they will be remembered.

The Nature of Forgetting

The nature of memory has long held a fascination for philosophers. Plato was intrigued by that part of our human nature which he called "memory." He described the memory process as a "soft wax": when we learn or experience something, it makes an impression and then hardens in the waxworks of the memory, while Aristotle regarded memory as a process of *association* and therefore central to all thought processes.

By the 1800's, associationism had become the dominant view of memory and cognition. According to associationists, memory consists of simple sensations or other psychological "elements," which are linked together into more complex assemblages, such as how chemical bonds associate atoms into compounds. The stronger the connections or associations, the better the recall.

Decay Theory. The first fundamental explanation for forgetting is the **decay** theory. Essentially, it holds that, after we have just heard something, such as a phone number, we form a memory trace, which begins to decay immediately. If we do not maintain the trace through use, the trace will disappear. If we use the phone number frequently, we will strengthen the trace, thus making the phone number a permanent memory. If we stop using that number and, often for a relatively brief time, the trace will be weakened and we will forget the number.

For all its common-sense value, decay theory could not explain forgetting completely, and it was discredited in the 1920's and early 1930's. Jenkins and Dallenbach (1924), for example, did experiments with subjects required to learn nonsense syllables. After learning the initial list, the subjects were tested at various intervals. One group of subjects took part in the experiment during the daytime, while another group participated at night. The daytime subjects stayed awake between the time they learned the list and the time they were tested. The subjects who participated during the night slept during the interval between learning and testing. Then, the two sets of subjects reversed their daytime and nighttime roles for the learning of the second list of nonsense syllables.

According to decay theory, there should have been no differences in forgetting between the daytime subjects and the nighttime subjects. However, there were differences indicating that forgetting was significantly more prevalent with subjects who were awake between the time of original learning and recall. Daytime activities *interfered* with the recall of previously learned content. Simple decay theory could adequately explain the inability to remember someone's name a few minutes after being introduced to that person, but it was not an adequate explanation for long-term memory loss, such as difficulty in remembering large amounts of information.

Forgetting as Repression. An early theory based on a psychoanalytic perspective is that proposed by

Sigmund Freud. He believed that all forgetting was due to repression, or that one theory that represses incidents associated with guilt or anxiety. Freud noticed that subjects who had experienced traumatic events in their childhood could not remember these events. However, events could be brought out through free association, dreams, and hypnosis. In Freud's work with patients he developed the method of free association in which subjects are asked to recite the "first thing that comes to mind." He assumed that through free association the real memory will surface before the active psychological processes work to repress or inhibit it. T

Free recall is still used by psychologists working with emotionally troubled patients. But repression is generally not credited to be the cause of day-to-day forgetting.

Interference

Retroactive Interference

When new learning blots out old learning, the phenomenon is called **retroactive interference**. In a typical experiment illustrating retroactive interference, subjects are asked to memorize a string of words or nonsense syllables designed List A. Half the subjects are then asked to memorize a second list of words or syllables called List B, while the other half rests or sleeps. After an interval, all the subjects are requested to write down as much of List A as they can remember. Those who rested or slept invariably do far better than those who had learned two lists. List B caused interference for List A. If you play a fair game of tennis, and then decide to take up badminton, you might find that habits acquired playing badminton interfere, with your ability to play tennis. (see Figure 3)

Proactive Interference

When old learning impedes new learning, it is called **proactive interference**. In a similar experiment illustrating proactive interference, half the subjects are asked to memorize List A and the other half is permitted to rest or sleep. Then all the subjects are given List B to learn. After an interval, the subjects who learned List A do far worse than those who learned only List B. In this case, the earlier learning—List A—interfered with the recall of List B. If you are studying Spanish and then decide to take French, you may find that first taking Spanish may interfere with your new learning of French. (See Figure 2)

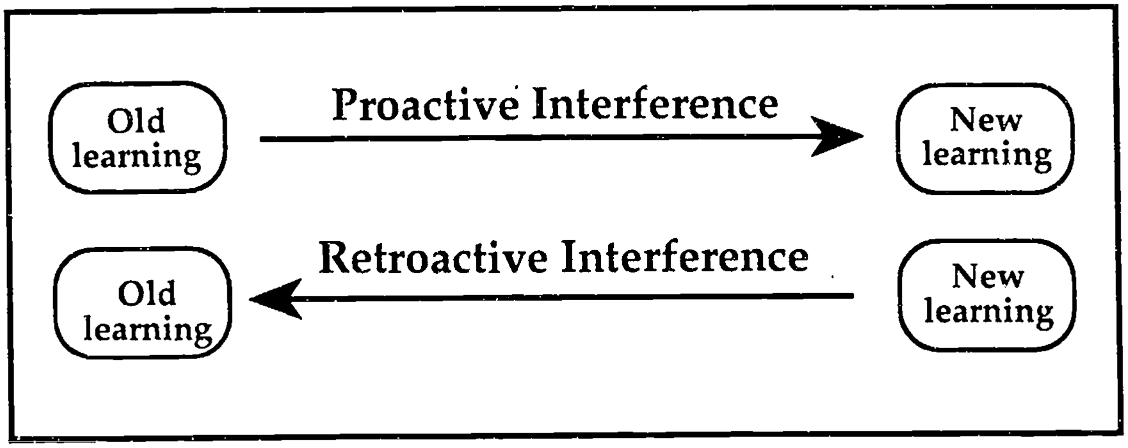


Figure 2

Retrieval Failure

Perhaps there is no "exit" from memory; material, once in, stays in. According to this view, when we've forgotten something, we've simply failed to locate the sought-after information within the vast storehouse. The information is still in storage; we are just suffering a retrieval failure, or inability to find the sought-after material.

The Retrieval Process

Consider the analogy of entering a darkened library. We cannot see all the books and journals, but with a flashlight we scan the shelves until we see the book we want to retrieve. When we are searching our memory, for, say, Lincoln's Second Inaugural Address, we are "calling up" that data and it will appear on our short-term memory "monitor." We can then interpret and use the information. (See Figure 3).

In a typical experiment, subjects are given a story to learn and then asked to recite the story at a later date. They usually have difficulty remembering the story, However, if they are given a retrieval aid in the form of a title (the story of the goa's), they can usually remember the story.

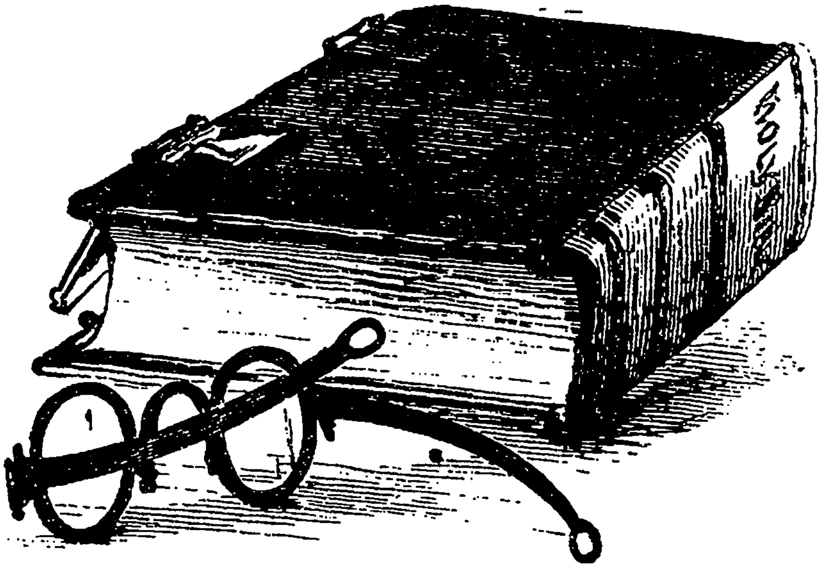
Whether forgetting is the result of *loss* of mate-

Six Comparisons of Short-term (STM) Memory and Long-term (LTM) Memory

Short-term Memory	Long-term Memory
1. Limited storage capacity	1. Large storage capacity
2. Easy to access, but information easily lost	2. Difficult to access, but storage is relatively permanent
3. Forgetting is largely a process of "decay"	3. Forgetting is largely a process of interference
4. Information is not well organized	4. Information is well organized
5. Errors tend to be acoustic (E.g, we recall "bark" when we hear "dark"	5. Errors tend to be substitution (E.g., we substitute "night" for "dark")
6. A "working" memory, of which we are conscious	6. Repository of knowledge and skills, of which we are not conscious

Figure 3

rial, interference, or whether it is a problem of *retrieval* is a question not yet settled by research (Schwartz & Reisberg, 1991, p. 496), but it is another possible explanation for forgetting. Some psychologists believe that information is never forgotten—we just have an inability to retrieve the information from a lack of a sufficient cue.



Chapter III

Representations of Knowledge

Neural Representations of Knowledge

The nervous system refers to more than just the brain. It refers to the various sensory systems that bring information from various parts of the body, as well as from the outside world. The human brain itself contains roughly 100 billion neurons, a considerable fraction of which are active simultaneously and interact with one another. The activity of neurons is caused by neurotransmitters, which are chemicals which flow through *synapses*. The strength of the neural activity is determined by the rate of firing. There can be hundreds of neural impulses per second. Neurotransmitters are chemicals that are much like hormones in the brain, which either increase or decrease the amount of firing.

At this level, the neural activity model is similar to the activity of the computer. In a computer, the basic unit of data is a "bit" that can have just one of two values—off or on, or 0 or 1. Computer code is a large sequence of 0s and 1s in a selected order. Thus, information is represented in the computer by combinations of on-off decisions. In humans, neural activity is characterized by varying intensity, much like the characteristic of variable strength of the on-off switching function of a computer.

The creation of the computer, with its internal command and control program, has provided a model of human information processing. The "computational paradox," as Gardner (1987) calls it, arises from the fact that a computer model of logic has provided a model of similar processes for the humans who created it (pp. 384-388).

Models of Human Thought

Experiences and knowledge of the world are all stored in long-term memory (LTM). It is material in LTM that enables us to recall events, solve problems, recognize patterns; in short, to think. Time and effort are required to insert information into LTM. Past events have to be pulled out with effort. Whereas short-term memory is immediate and direct, long-term memory is labored and strained.

From short-term memory:

What were the first words of this sentence?

From long-term memory:

What does the sentence mean?

Whenever you understand some phenomena, such as how an electronic calculator works, what causes lightning, or the solution to a problem in geometry, you have formed a mental representation of that understanding. The term "mental model" is used to refer both to the content of a mental representation as well as the *processes* that construct and manipulate them.

Given that information is encoded and stored in long-term memory, how are these memories stored? There are a number of theories related to how mental representations are held in long-term memory.

Tulving

Tulving proposed that there are two forms of memory: **episodic** and **semantic.** Semantic memory holds all the information we need in order to use language and any conceptual information. It includes not only words and the symbols for them, but their meaning, and what they represent. Semantic knowledge is all basic conceptual information. If we think of a bird, we think of the physical characteristics of a bird, as well as the fact that a bird is a mammal, can fly, and is located in various parts of the world. Semantic memory contains such things as the rules of English grammar, chemical formulas, rules for long division, knowledge that winter follows autumn—facts that do not depend on a particular time or place, but are just basic information.

Episodic memory, in contrast, contains information about how events happened and when they occurred. It is our memory for personal history, such as "I left for Europe the day after I graduated." Episodic memories are often very vivid, and are personal for each individual. Tulving (1979) noticed that people remember events chronologically. For example, you might not remember all the people in the grocery store who passed you by, but you are likely to remember the exact path you took through the store and the order of the items you bought.

Network Models of Long-term Memory

Anderson's ACT* Model

Another model—the Adaptive Control of Thought—was proposed by John R. Anderson of Carnegie-Mellon University. The model is based on a series of network models that he developed over a period of about 10 years. The most current version is called ACT* (called "Act-star"), a modification of the original ACT model (Anderson, 1983; 1993).

Anderson does not agree with Tulving's distinction between semantic and episodic memory. Instead, his model proposes a distinction between **declarative knowledge**, which refers to factual information that is gathered through day-to-day learning; and procedural knowledge, which refers to activities which involve steps, such as riding a bicycle, making a floral arrangement, and doing long division. In Anderson's model, declarative knowledge combines episodic and semantic memory. (See Figure 1)

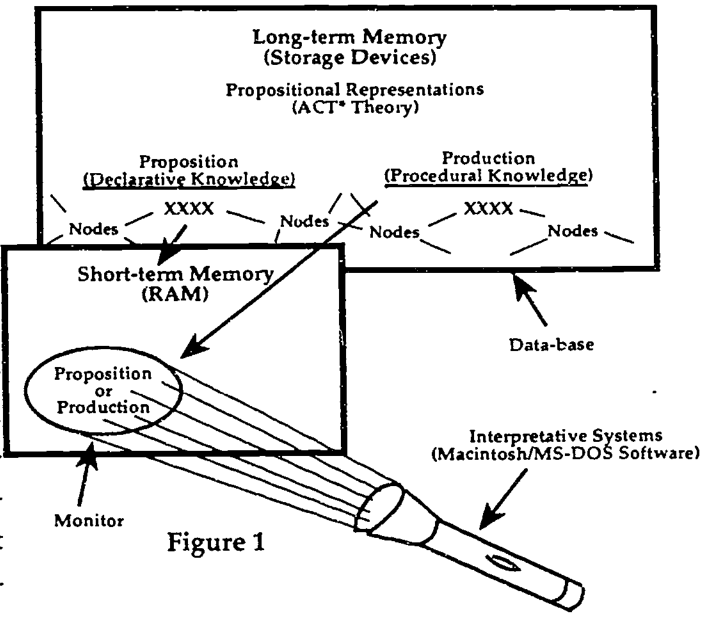


Figure 1

Some authorities include a third component, metacognitive knowledge, which refers to a deliberate and conscious control over one's thinking processes (Schunk, 1991).

Declarative Knowledge

Declarative knowledge consists of a network of nodes connected by links of varying intensity. Nodes are information fragments that comprise the basic units of knowledge. The size and content of nodes may vary. A node may be represented by a single concept or example, or by an entire, "complete idea," which is called a **proposition**. (McAleese, 1990). A proposition is the smallest unit of knowledge that can be judged either true or false. Thus, "tomatoes," "satellite," and "junk food" are not propositions because they cannot be judged true or false (they are concepts); but the knowledge represented by the sentences "Water makes iron rust," "All men are created equal," and "The cat climbed the tree," are propositions. According to Anderson, (1985), the meaning of a sentence is represented by a propositional network, which is a pattern of interconnected propositions (see Figure 2, on next page).

At any given time, some of the nodes are active

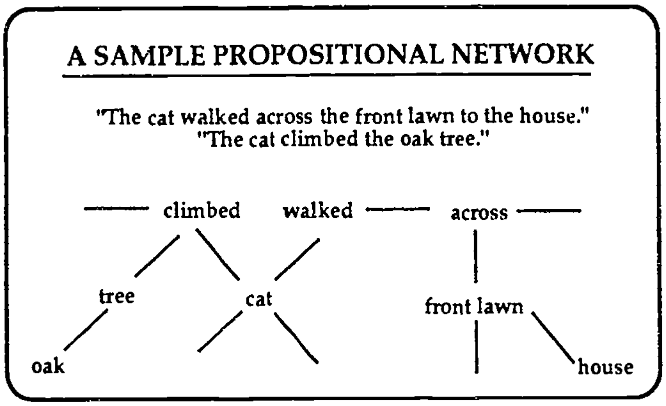


Figure 2

(i.e., the propositions stored in the nodes are being thought about), while others are inactive. As the learner shifts his or her thoughts from one subject to another (e.g., from thinking about current upheavals in the Middle East to what to buy at the supermarket), relevant nodes are activated and irrelevant nodes are bypassed. Propositions that share elements are related in networks. Unlike the computer, which simply stacks information like items in a warehouse, the propositional network stores related bits of information closer together than unrelated bits.

Procedural Knowledge

Declarative knowledge is relatively static, whereas procedural knowledge is dynamic. When procedural knowledge is acted upon, the result is not simple recall of information but a transformation of information into a **production**. For example, the product of procedural knowledge about the teaching of reading might be a lesson plan. The input information ("I need to prepare an exercise for tomorrow's reading class; I will need to prepare the students with practice locating the topic sentence") has been transformed to produce an output or performance, that looks quite different from the input. Thus, procedural knowledge is used to operate on information in order to transform it.

The acquisition of procedural knowledge can be described as an "IF.......THEN......." production:

> **IF....the goal is to subtract the digits in a column of numbers, and the subtrahend is larger than the minuend,**
> **THEN.....set a subgoal to borrow.**

This algorithm states the goal, the state of the problem represented in working memory, and long-term declarative knowledge about the relative magnitude of digits. If the problem described in the "IF" portion of the production is satisfied, the production's action, the "THEN" component, can execute, and a cognitive process can occur.

Once it is well learned, procedural knowledge operates in a fast, automatic fashion. For example, a skilled reader can scan sentences very rapidly in the process of transforming print into either an auditory or meaning representation, or both. There is evidence that combining declarative and procedural knowledge, acting out while verbalizing the concept, improves performance in later recall (Cohen, 1989).

Metacognitive Knowledge

Having the requisite declarative and procedural knowledge to perform a task does not guarantee that students will perform it well. Consider a student about to read a social studies text. She knows what to do (read a passage in the text), she understands the information on the page (declarative knowledge), and she has been taught how to look for main ideas, note significant dates and events, and make inferences about significant ideas (procedural knowledge). When she starts reading, however, she proceeds through the text at a slow, deliberate pace, reading every word and sentence at the same rate of speed and intensity. As a consequence, she arrives at the end of the passage without a clear understanding of the main points and issues.

This is a common situation with many students. They have been taught to vary their reading speed and comprehension tactics, but they either skim the entire passage or plod through, word by word. Metacognitive knowledge is awareness of *how* to adjust learning and comprehension rate according to the level of difficulty and the objectives of the assignment. With good readers, this knowledge becomes a permanent, almost automatic capability in long-term memory. With poor readers, this self-adjustment behavior can be learned and utilized effectively.

Metacognitive knowlege is awareness of one's own learning. It is the ability to focus on all forms of thought (not just reading). Incidentally, this is one area in which humans are vastly different from computers. Humans have an awareness of their interactions with the environment and are able to modify their learning potential dependent on their interests.

The Conditions of Learning

The conditions for learning declarative and procedural knowledge can be quite different, though one might lead to another. One example of this occurs when one is learning word processing on a computer. At first, you do a lot of talking to yourself, which indicates that you are retrieving a declarative representation to understand the system and guide the procedures. Later, as you become faster, the declarative information will be bypassed and procedural representation will begin to operate by rote.

The construction of test items utilizes both modes of retrieval. Test items emphasizing declarative knowledge are constructed either for recognition or for recall. But test items that emphasize procedural knowledge require the learner to do something other than recognize or recall, such as solve a problem in long division or balance a chemical equation. Essay questions may tap both processes: Asked to compose an essay about life on a plantation prior to the Civil War, the student must retrieve facts about plantation life (declarative knowledge), organize all the information, and then write a description of plantation life clearly and persuasively (procedural knowledge).

Metacognitive knowledge is utilized in the skills required to be a good test-taker, such as skimming skills, ability to find information in one item that can be applied to another, and the adjustment of time constraints to length and difficulty of the test.

The Nature of Concepts

We acquire knowledge and experience in various ways: by direct experience through our senses, through ideas conveyed by symbolic language, and through knowledge gained in everyday living. Words alone cannot portray the richness of a Beethoven string quartet, sunset over water, or an exhilarating moonlight swim. These are sense-laden experiences, and words cannot convey their meaning to us. The world of direct experience is necessarily quite limited, and the complexities of modern living require us to deal with what is not immediately present to our senses. As Walter Lippmann (1949) wrote:

> **The real environment is altogether too big, too complex, and too fleeting for direct acquaintance. We have to reconstruct it on a simpler model before we can manage with it. Men must have maps of the world.**

But one must know how to interpret a map. Language helps us to form ideas about experiences and objects both concrete and abstract. However, direct and indirect experiences and activities are necessary for the beginner—especially children—to understand the meaning of words. Language is the way we convey broad ideas, but the first step in mastering language is the acquisition of the building blocks of language and thought, called **concepts.**

Concepts can be objects, events, or ideas, and they are typically defined in the dictionary with three characteristics: (1) class, or category; (2) properties, or characteristics; and, (3) example (see Figure 3, on next page).

A concept is a "class of classes." Concepts are classes of stimuli (information) that group together on the basis of some common characteristic, or **attribute.** The concept of "apple" has attributes that

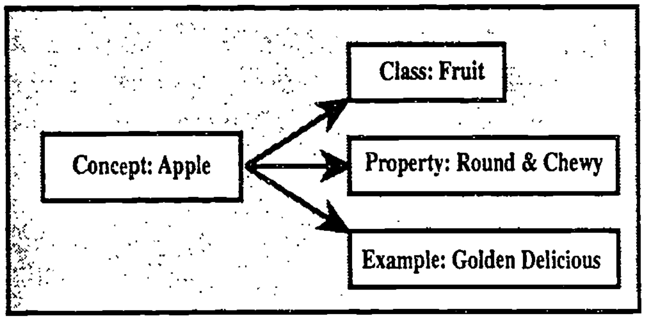


Figure 3

are characteristic of all apples. Attributes can refer to size (an ocean is bigger than a lake), shape (a triangle has one shape, a square another), color (oranges are orange, apples are red), or function (desks are primarily for writing, while tables are primarily for eating). Some attributes are necessary to define a concept, while others are not. The necessary attributes are known as **defining attributes.** Perhaps the best way to explain this idea is to look at three classifications of concepts: **conjunctive, disjunctive,** and **relational.**

Conjunctive Concepts

A **conjunctive concept** must include all the relevant characteristics or attributes. The child learning the concept "elephant" finds that an elephant can be recognized by its distinctive trunk, floppy ears, and immense size. A creature that is like this in all respects but has no trunk is not an elephant.

With a conjunctive concept, the learning task is not especially difficult. For example, if the child has never had any experience with a coconut, the easiest thing to do is show her one, cut it open, and let her take a sip of the juice or a bite of the meat. If the specific item is not available, or if it is not practical to bring it into the classroom, a replica of the item is the next best thing.

Disjunctive Concepts

A **disjunctive concept** has one of several alternative characteristics. A foul in basketball represents a member of this concept class. A foul may be called for charging, elbowing an opponent, or disrupting the game. Multiplicity of meaning makes disjunctive concepts difficult to learn.

Relational Concepts

Relational concepts involve relationships or contrasts between elements, and are sometimes very difficult for children to learn. "Larger than" and "similar to" are examples of relational concepts. Pigeons, rats, and monkeys are all capable of solving relational problems, but not so rapidly as humans. Concepts involving relationships are common in everyday life, but young children often experience considerable difficulty in understanding, for example, that the same town is west of one city and east of another.

In addition, as Horn (1937) once pointed out, children often do not give reasonable interpretations of concepts of quantity, distance, and time, such as "many," "few," "far," "near," and "a long time ago." Apparently, children find it difficult to think in relative terms and would prefer to assign definite ranges of numbers to such words.

In teaching children these relational concepts, the main problem is to provide numerous examples so that they can contrast them with what they already know (Murray & Mayer, 1988). For example, 100 items might be "many" in some situations and "few" in other contexts. It may help to use an unusual context in order to illustrate concepts of large and small in sharp relief. Imagine an astronaut on the moon meeting humanlike creatures whose average height is 6 inches!

Concepts that are both disjunctive and relational pose a more serious challenge for the teacher. Words such as "love," "hate," "teamwork," and "democracy" must be taught by successive approximations, and the process moves from words used in a denotative sense to their use in a connotative way. Explicit dictionary definitions of nouns—especially specific objects—are examples of denotative mean-

ings. To learn the denotative meaning of "dog," the child must know which patterns or properties are important in determining whether or not an animal is a dog. But, in addition to its denotative meaning, "dog" has a connotative meaning: "dogness," which is a more abstract and complex version of the child's knowledge of a dog. Such qualities as "friendly," "faithful," "vicious," "man's best friend," and "floppy" are connotations that a child might have about dogs that depend on the personal experiences he or she has had with dogs. Although these are associated with "dog," they are noncritical attributes and are mostly irrelevant as far as denotation is concerned.

Prototypes: An Alternative to Definitions

Not all theorists believe that concepts have well-defined boundaries and that all instances of a concept fit equally well into a particular category. For example, some of the colors we call "green," seem greener than others. Similarly, some cars seem more "car-like" than others, some balls more "ball-like," and some coats more "coat-like." Rosch (1977) and other contemporary researchers (e.g., Busemeyer & Myung, 1988; Nosofsky, 1988) have shown that many concepts have a **prototype**, which might be considered an "average" of the various characteristics that comprise that concept (Schwartz & Reisberg, 1991). For example, if we asked a group of children to cite a large number of instances of the concept of bird (e.g., robin, sparrow, eagle, hawk), we would probably find that a bird, such as a robin, is most typically "bird-like." In one study, subjects were asked to agree on sentences provided by an experimenter. The time it took to respond was then measured. The subjects answered very rapidly to a sentence "A robin is a bird." However, they were less rapid when they responded to "an ostrich is a bird." Experimenters noticed that subjects matched the birds to some "idea" of a bird in their heads. The more like the typical bird, the quicker the response.

Busemeyer and Myung (1988) have argued that most concepts are represented in memory as prototypes. These prototypes contain the most typical attributes of concepts—they are "inside" the category—and the various instances of a concept share these attributes to some degree (e.g., robins and sparrows clearly share many attributes). In their view, the boundaries between concepts are ill-defined and judgements about borderline cases (e.g., ostrich as an instance of bird or whales as an instance of fish) are very difficult. Concepts that do not have clear boundaries are called "fuzzy" (Neisser, 1967). Concepts may be fuzzy for several reasons (Rey, 1983). One is that some items cannot be classified because they have the attributes of two or more classes; for example, the organism Euglena as *plant* or *animal* and platypus as *mammal, reptile,* or *bird* (Howard, 1987). A second contributor to fuzziness is that one may not know the defining attributes of the concept sufficiently well to classify the least typical instances; to illustrate, leeches are often classified as insects (McCloskey & Glucksberg, 1978).

E. L. Thorndike once said that normal children need at least thirty exposures to a concept before they know it "cold." With words that are highly abstract, such as "democracy," thirty exposures is the minimum required for learning, providing only the sensory recognition of the appearance and sound of the word. Understanding its *meaning* is quite another matter, considering that highly educated, verbally sophisticated adults can hardly come to agreement on what the term "democracy" means.

A variety of alternate presentation strategies can be used to supplement the standard definition, plus examples/nonexamples strategies used in classification training (Tessmer *et al*, 1990). Many of these strategies have been advocated by instructional designers over the years. For example, displaying coordinate concepts in structural outlines, such as concept trees, has facilitated coordinate concept classification (e.g., Tessmer & Driscoll, 1986), and may be particularly effective with adult learners (Bower, 1970). For classification practice, concept games and simulations represent a little-used strategy that puts the learner into scenarios that elicit classification performances in ways that differ from standard concept example practice (Tessmer *et al*, 1989). Particularly, concept simulations mimic the real-world situations in which the learner will use concept classification, increasing the probability of transfer.

Generally speaking, concept attainment becomes more difficult as the number of relevant attributes increases, as the number of values of these attributes increases, as the information load that must be handled by the subject in order to solve the concept increases, and as the information is increasingly carried by negative rather than positive instances (Carroll, 1964). The more abstract a concept, the more examples and experiences are required for a clear understanding. Each experience or bit of information relating to a concept functions as a partial approximation. When enough of these bits and pieces are brought together, they can form a concept that accounts for most, if not all, of the possible attributes involved in that term. The objective is to get your students closer and closer to the real thing.

Concepts help us to reduce the complexity of the world by allowing us to put new information in already existing "compartments" of knowledge. Some theorists believe that concepts are stored as declarative and procedural components in a network-like arrangement. Some theorists see concepts as nodes in a network (Anderson & Pirolli, 1984), while others consider concepts as parts of a larger, more complex schema (Gage & Berliner, 1988).

A rich background of concepts, both simple and complex, is necessary for progress in both reading and problem-solving (Recht & Leslie, 1988). For this reason, the development of concepts should begin early in the educational process. The teacher's task is to help children learn correct concepts by selecting from a wide array of instructional methods. The more ways in which a child can experience a concept, the more that concept becomes an established part of her repertoire of concepts and the more useful it becomes as a background for growth in reading comprehension. Teachers at the secondary-school level especially are often under time constraints imposed by the curriculum, and as a result tend to load too many complex concepts on students, rather than concentrate on fewer concepts taught in greater depth.

Schemata

Concept theories focus on questions about how units of knowledge are stored in memory. While these questions are important, many cognitive psychologists have become more interested in how knowledge is used to *interpret* experience. They have proposed that knowledge is organized into complex representations called **schemata** (singular: schema), which control the encoding of new information, the storage of information in memory, and the retrieval of stored information (Rumelhart, 1980). A schema may be a network, or grouping of concepts.

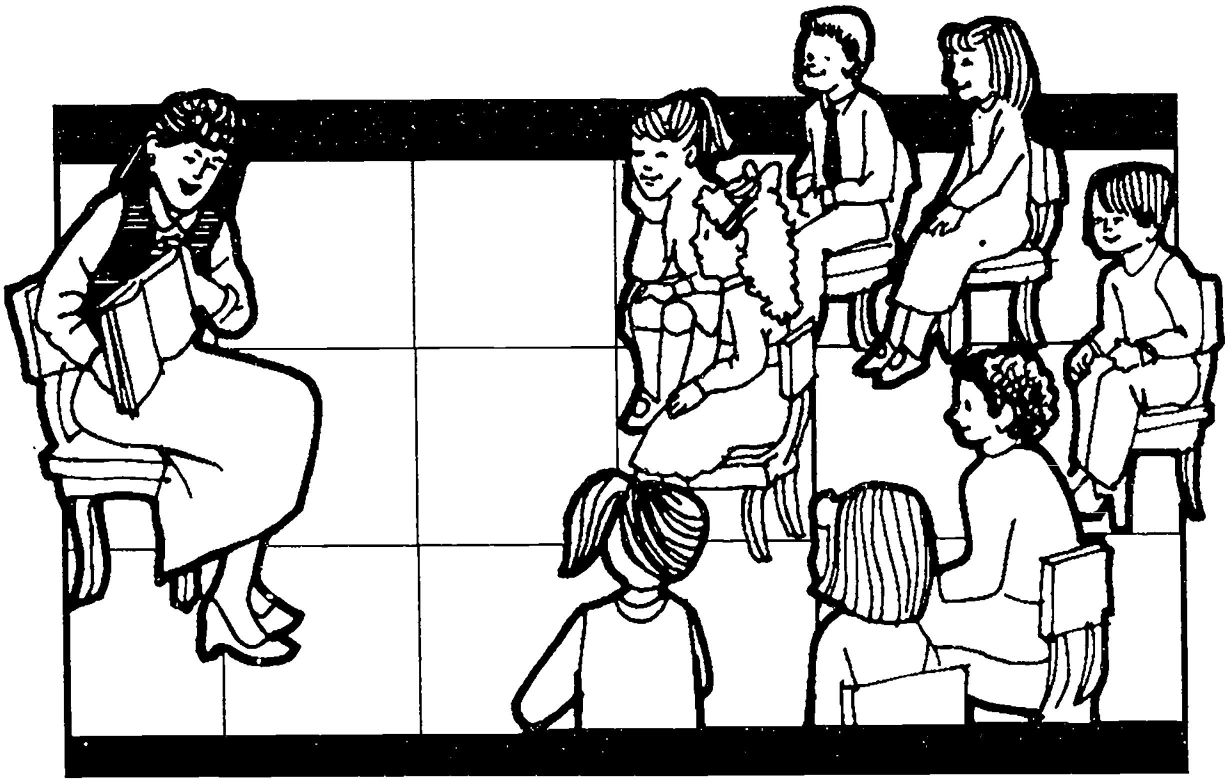
> **Schemata are large, basic units for organizing information. Schemata serve as guides that describe what to expect in a given situation, how elements should fit together, the visual relationships among elements, and so on. A schema is like a model or stereotype (Woolfolk, 1990).**

The term "schema" was first defined by Bartlett (1932, p. 201) as an "active organization of past reactions which must always be supposed to be operating in any well-adapted organic response." His now-classic experiments illustrate the existence of schemas in the comprehension of information. In the experiments, the first subject read a folk story (*The War of the Ghosts*) from an unfamiliar culture, reproduced the story from memory, and gave this account to the second subject. The second subject read subject one's version, laid it aside, reproduced the events, and handed that version to the third subject, and so on. By the time the story reached the tenth subject, it was no longer a folk story about mythical visitors. Instead, it had become a fishing trip!. The personal narrative aspect of the story—the ghosts, and other significant events—had been dropped from the story, while some details were exaggerated.

Bartlett found that the repeated stories had changed in systematic ways: Unfamiliar information was dropped, a few details were retained, and the story became more like the reader's expectations. In other words, information was changed to fit the existing schema and to become more coherent to the individual.

Types of Schemata

We have schemata for eating in restaurants, attending a football game, or visiting our relatives. The knowledge, or procedures associated with each of these activities is our schema for the activity, which is interconnected with other schemata. The knowledge in any schema is, therefore, interconnected with other schemata. One's schema is our personal understanding or awareness of a general



concept. However, the schema for an event differs from the concept of that event. The schema ties together a number of concepts, which provides a formal definition and understanding of the events around us. There are two areas of schema research: scripts and goals and plans.

Scripts

One popular form of schemata is the script. Scripts are mental representations of causually-connected actions, props, and particpants that are involved in common activities (Galambos et al, p. 19). A common example is the restaurant script. Other scripts might include grocery shopping, bus riding, and throwing a birthday party.

In a script there is the activity. An activity is a self-contained series of actions pertain, to attain a goal. In the restaurant example, the activity would be reading the menu and being seated, ordering food to achieve the goal of eating a meal. In typical experiments of scripts, subjects are given statements related to activities in the script. For example, "is ordering part of going to the restaurant," would be answered very rapidly.

In script studies, events are r emembered only if they are distinctive. Distinctive refers to how often an event typically occurs in the activity. A distinctive event in a restaurant scene may be standing up to eat, or receiving Mexican food in a Chinese restaurant. However, standard events such as being seated will often be forgotten since they are standard and not distinctive events.

Another aspect of script theory is called **centrality events.** Certrality is aspects of the script that are necessary for script to be activated. Events which are central to a script help individuals locate the appropriate knowledge structure in their head as well as create expectations of the outcome. For example, you may not hear that the meal was served at a restaurant. However, if later asked to recall someone's telling you about it, you will most likely say, "The meal was served and eaten."

Thus, the central components of a knowledge structure provide a set of default values that are present at input and will provide the ambiguous information if not provided.

Goals and Plans

Goals and plans are similar to scripts theory except they are less specific. While the events in a ordering from a restaurant may be clear, some events as in proposing marriage or applying for a job are less specific. The activity of "planning" involves a choice among alternative plans and that some subplans will need to be developed as well.

Plans as related to goal attainment are a result of rely ing on a knowledge structure or explanation, and moving to structures or schemas when this fails. One way to look at how plans and goals are formed is through script failure. Suppose you hear that a friend went to a restaurant but came h ome without eating anything. You will begin to look for an alternative explanation based on experiences or knowledge related to restaumats, your friend, or anything related to the event.

1. **The restaurant closed.**
2. **The restaurant didn't have what he wanted to order.**
3. **He had an angry reaction to the food served.**

Thus, the related context or related schemata affects your explanations. Explanations related to the restaurant event will get the most consideration, while less related explanations, such as "he broke his leg on the way there," would get less considation.

Both script and plans and goals help us to interpret the world around us. For example, if you read a story about a restaurant and read the word "serve," you are unlikely to think of a tennis serve.

Schema Activators

As we mentioned earlier, experts in reading instruction long have emphasized the value of fashioning statements from topic sentences, bold-faced or italicized headings, and theme statements embedded in the text. Any system of organizing or interpreting the information contained in a passage is referred to as a **schema activator**. Activators are a means of encoding information so that it is readily retrieved when needed. The schema activator does not have to be material organized by the reader, it can be built into the instructional method. In an experiment by Bransford and Johnson (1972), subjects read a short, difficult-to-interpret passage and were shown a picture which supplied a context for the text before or after reading. The control groups simply read the passage once or twice but did not view a picture related to the content. Those learners who saw the contextually relevant picture before reading about it achieved comprehension and recall scores which were significantly higher than any of the controls. It appears that a well-designed schema activator can cue the reader to form an applicable schema structure within which to process and interpret the new material. This advantage can result not only from topic statements, questions, or pictures, but also by placing headings in the text (Dee-Lucas & DiVesta, 1980), putting quotation marks around key phrases or sentences critical to understanding the material (Pratt *et al*, 1981), and studying an outline of the text (Mannes & Kintsch, 1987).

Chapter IV

Graphic Representations of Knowledge

The expression— "One picture is worth a thousand words"— has been around for about a thousand years, but it has not been a major consideration in education. Schools have honored the tradition of written language by putting reading and writing in the center of the curriculum, which has in turn contributed to the belief that we think best in *words*. Today, one of the most widely-used assessments of general academic ability is the vocabulary subtest of achievements tests. The *Scholastic Aptitude Test* has two subtests: verbal and mathematical, reflecting the view that higher-order thinking is the ability to use language and numbers. If we broaden the definition of thinking beyond manipulation of language symbols, we are talking about *conceptual* thinking. The reality of the electronic environment around us has elevated the *visual* and *graphics arts* as a means of conveying human knowledge and experience. Images comprise our most vivid memories, as well as being the basis for imagination—the creation of visions for the future. All scientists, mathematicians, and artists recognize the importance of graphics to their work.

Beginning in the 1960's, computer graphics has led to revolutionary discoveries in fields such as medicine, mathematics, and biology. Graphics offer a powerful way to capture certain phenomena, and it has contributed to major breakthroughs in our picture of the world and the principles of physics and matter. For example, Einstein developed his theory of relativity by imagining himself riding on a beam of light. Only that way could he conceptualize that light has properties of both particles and waves. Graphics, charts, histograms, even doodling, are ways to convey, or express concepts and principles in an alternate form to prose. Graphic representation is fast becoming a standard in areas such as computer applications. In the evaluation of computer screens, early pioneers, like the Apple Macintosh, realized that a simple look was important for inexperienced users. In fact, one of the members of the Macintosh development team was a visual arts designer, with a particular talent for creating icons (Levy, 1994). Today, the graphic-user-interface (pronounced "goo-ey") has become the standard with respect to PC design, as evidenced by the visual appearance of Microsoft's *Windows 95* operating system. As Eisner (1990) notes:

> **. . . . the fact that charts, diagrams, schematics, and spread sheets are very useful ways to display information has been quickly understood by IBM, Apple, and Toshiba. They waste no time pointing out to prospective customers how much more readable and saleable their products will be if they use graphics. In this respect, they are far ahead of education** (p. 77).

Concept Mapping*

Many times when we try to think about a word, an object, or even an abstract idea, we remember an image of that thought. This is sometimes referred to as "seeing in the mind." In this form of concept formation, individuals "learn" by augmenting, combining, and organizing a collection of cognitive maps,

*In current literature there are various terms or phrases for concept maps, such as graphic representations (Jones *et al*, 1988), semantic mapping, graphic organizers (Hawk, 1986), information mapping (McAleese, 1986), webbing (Bromley, 1991), and networking (Holley & Dansereau, 1984).

many of which are overlapping and most of which are interconnected by a complex network of associations. No two individuals have exactly the same set of associations; hence, no two individuals picture things in exactly the same way.

There appears to be two types of cognitive maps, or imagery—one that preserves the visual details and one, not tied to the visual modality, that highlights spatial relationships (Anderson, 1990, p. 86). Since the teaching of concepts involves focusing on similarities, differences, and generalizations of concept attributes, the study of images connected in the **concept map** has been growing in popularity (Winn, 1991).

A concept map is a two-dimensional, hierarchical organization that conveys the structure of a construct, a paragraph, a unit of study, or a discipline. According to McAleese (1986), the concept map is similar to a terrain or road map. The concepts within the total network are roughly comparable to towns or cities, while relationships are like roads or streets. Relationships (called "links" in some of the literature) are the way which in which connected concepts are like travel routes between places. The total concept map is a guide for comprehension, as a road map is a guide for travel.

Examples of concept maps include spider maps, network trees, fishbone maps, compare/contrast matrices, and cycles (Jones *et al*, 1988). (See Figures 1 through 4 on next page.)

Concept maps help the learner to comprehend, summarize, and synthesize complex ideas and organize verbal statements. Reading with an appropriate concept map in mind can assist one to highlight important ideas and facts as well as detect missing data and unexplained relations. Consider, for example, how many words it would take to describe a complex social or political ideology, "high-tech" device for industry, living organism eco-system, or the methodology of solar heating. A concept map can be used to show at a glance all the essential parts of a whole and their relationships. At a glance, the viewer "sees" all the parts within the network.

Finally, a concept map at a glance provides the hierarchy from which one can choose the major points for the outline of a speech.

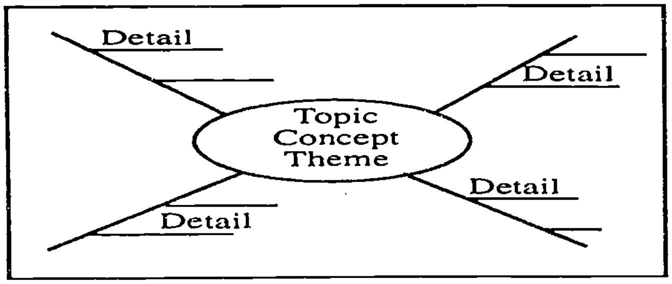
Hierarchical Concept Mapping

Constructing a concept map may help students become actively involved in processing information. Concept mapping fosters nonlinear thinking, unlike prose summaries and logical outlines. For example, concept maps such as matrices or trees can be read from left to right as well as from top to bottom, thereby providing in-depth processing and rich contextual associations. Further, concept maps require input from two modes (visual and verbal) rather than just one. Once a graphic has been constructed, conventional summarizing—a task that students typically find difficult—is relatively easy (Jones *et al*, 1988).

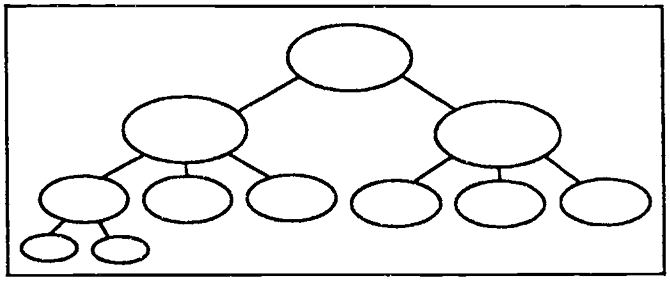
A good way to start—if you have no exerpience with concept maps— is by developing a hierarchy (Stice & Alvarez, 1987). Beginning with a familiar word (e.g., dog, chair, book), "brainstorm" information about the word (e.g., bark, have are animals, are pets, have fur, etc). Then, write out the words and rank them from general to specific. As a general hierarchy begins to form, one can begin to draw out relationships on the board, using some words as links (Source: Stice & Alvarez, 1987, p. 89).

HYPERMEDIA

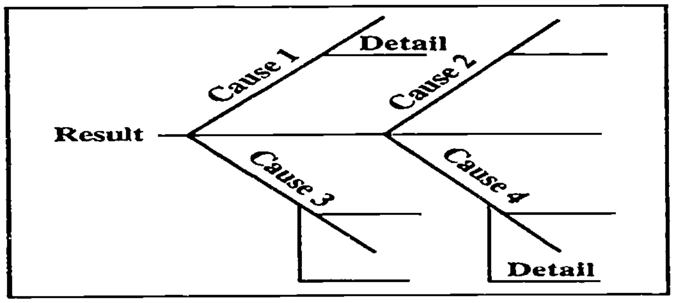
When we learn from print, we learn in a format made traditional by early Roman and Greek documents and the development of the printed page. The layout of printed information is limited by the organization of information on a page. When we write out information in conventional textual form, the process is generally linear: we open with a heading, then add finer details under subheads as we go down, and end with a summary paragraph. Even in



(1) SPIDER MAP: Used to describe a central idea; a thing (a geographic region), a process (meiosis), a concept (altruism), or a proposition with support (experimental drugs should be available to AIDS victims). Key frame questions: What is the central idea? What are its attributes?



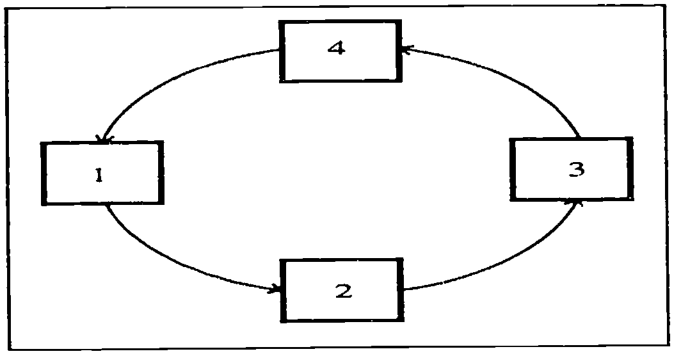
(2) NETWORK TREE: Used to show causal information; a set of circumstances, a hierarchy (types of insects), or branching procedures (the circulatory system). Key frame questions: What is the superordinate category? What are the subordinate categories? How are they related? How many levels are there?



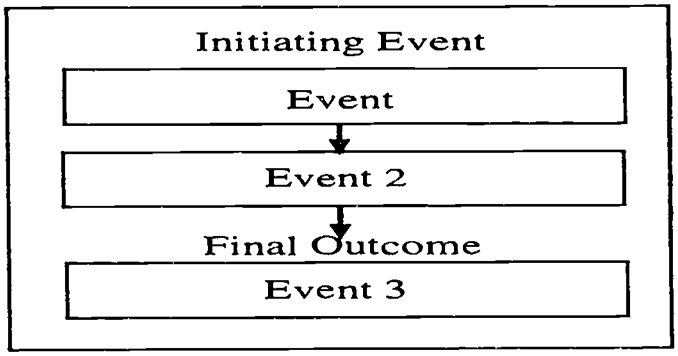
(3) FISHBONE MAP: Used to show the causal interaction; a complex event (an election, a nuclear explosion), or complex phenomenon (juvenile delinquency, learning disabilities). Key frame questions: What are the factors that cause X? How do they interrelate? Are the factors that cause X the same as those that cause X to persist?

	Name 1	Name 2
Attribute 1		
Attribute 2		
Attribute 3		

(4) COMPARE/CONTRAST MATRIX: Used to show similarities and differences; between two things (people, places, ideas, etc.) Key frame questions: What things are being compared? How are they similar? How are they different?



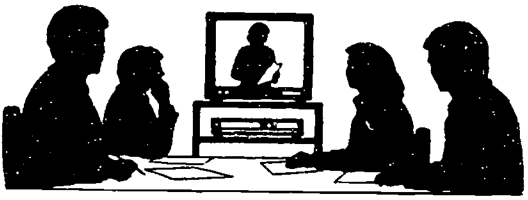
(5) CYCLE: Used to show how a series of events interact to produce a set of results again and again (weather phenomena, cycles of achievement and failure, the life cycle). Key frame questions: What are the critical events in the cycle? How are they related? In what ways are they self-reinforcing?



(6) SERIES OF EVENTS CHAIN: Used to describe the stages of something (the life cycle of a primate); the steps in a linear procedure (how to neutralize an acid); a sequence of events (how feudalism led to the formation of nation states); or the goals, actions, and outcomes of an historical figure or character in a novel (the rise and fall of Napoleon). Key frame questions: What is the object, procedure, or initiating event? What are the stages or steps? How do they lead to one another? What is the final outcome?

serious conversation, we tend to "start from the beginning," and proceed sequentially and chronologically to the end of the story.

Compare for a moment, how the same story is structured on the nightly television news program. Does the story unfold in a linear progression? No, it is structured and presented according to the importance of the "bytes" of information to be communicated within a specific time frame. We see an opening image, usually a videotape clip, and then we hear the voice of the newsperson who may begin with a "headline" that is intended to "grab" our attention. In print, we have a linear sequence that moves, at least theoretically, from an overview, through both elaboration and details, to a summary. On television news, the sequence is a series of succinct statements and visual images presented according to their communication value. The newscast does have a beginning and an end, but the information is arranged as a display of visual images and brief sound bytes.



Currently, electronic imagery is changing the way we receive and process information. The attention of students is not going to be drawn spontaneously to conventional print, to talking teachers, to the comparative drabness of the school environment, when they have access to a moving, colorful, quickpaced, even outrageous environment of images (White, 1987b). Edlectronic imagery may be the answer to the problem of managing information that has become too complex, too intertwined or inaccessible by conventional means. One popular medium which is finding its way into schools and colleges is hypertext, which is a non-linear, computerized text that allows immediate access to a very large information base.

Hypertext has been variously characterized as nonlinear prose, interactive print, or dynamic text using electronic capabilities to overcome the limitations of linear, printed text. The two elements of a hypertext system are:

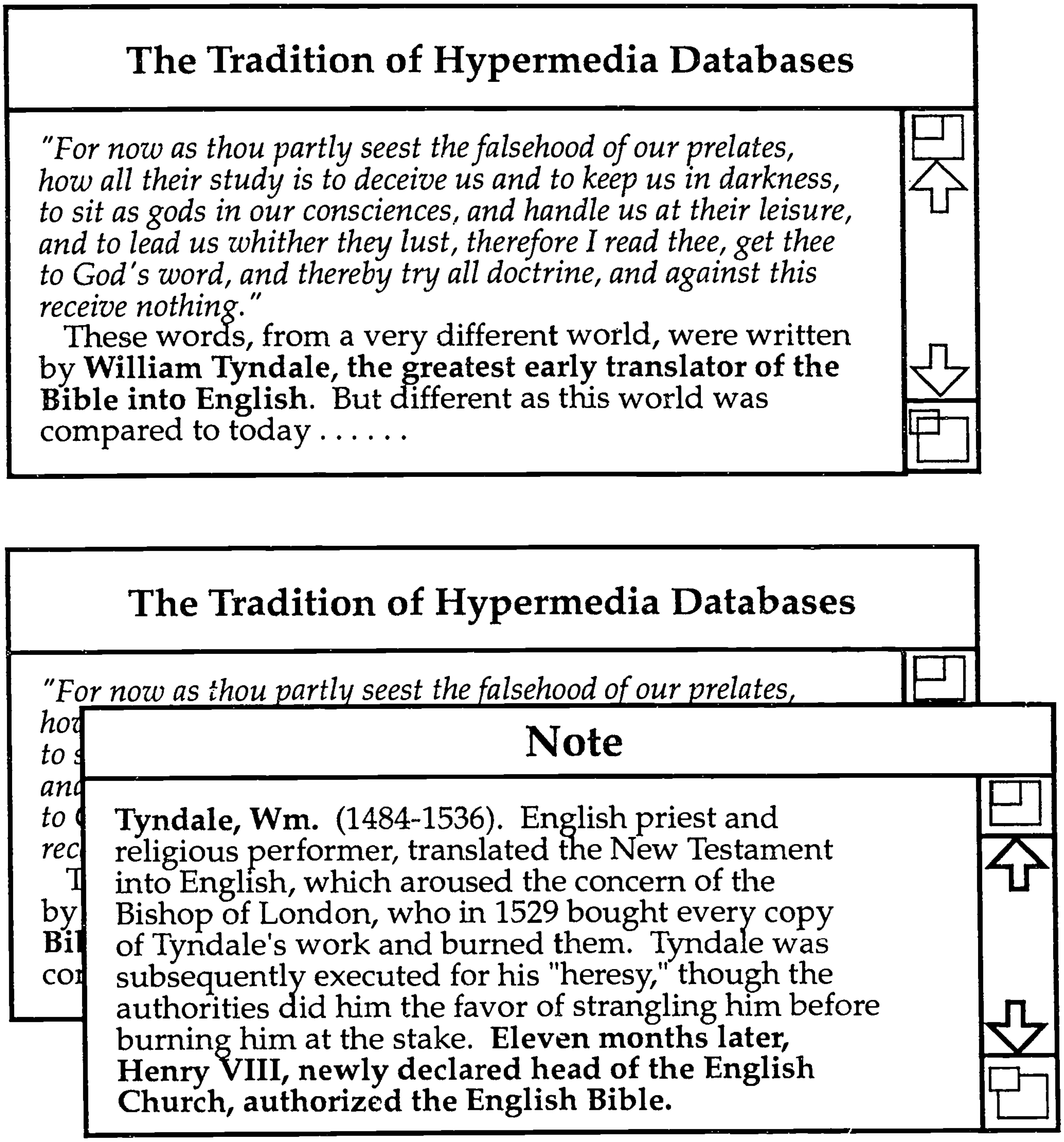
Modules: **Pools of information collected in one anthology, labeled or typed, and electronically stored as nodes in a database.**

Webs: **The patterns of links among the nodes. The links can be predefined by the hypertext system designer, or the user(s) can establish the links as part of walking through the information domain (Carlson, 1990).**

In a typical hypertext system, the reader views text and graphics on a computer screen. These items are linked to other information chunks (which are either text, graphics. pr evem video clips). The linked items are highlighted in some fashion. By selecting ("clicking on") the items, the user "jumps" to, or calls up, the attached information in another node.

One authority, Carr (1988, p. 7), compares this process of accessing data to the traditional procedures of "looking up an entry in an index, reading the entry, looking up another entry in the index, reading that entry, looking up another entry. . ." By contrast, hypertext is a faster, more efficient form of data retrieval by which the user can browse through the information, moving quickly from one place or idea to another, or dthrough a web of associations.

Consider this example (see Figure 7). The text is a prose passage that appears on the screen as it would in a book. Some of the words are highlighted by boldface, and by so doing suggests that there is a note or lengthier reference on that phrase. To retrieve that note, the reader points with the cursor at the highlighted text and presses the mouse button. A second window then opens on the screen and presents a new paragraph for the reader to consider. The reader examines the note, presses the button to vanish the note,



The Tradition of Hypermedia Databases

"For now as thou partly seest the falsehood of our prelates, how all their study is to deceive us and to keep us in darkness, to sit as gods in our consciences, and handle us at their leisure, and to lead us whither they lust, therefore I read thee, get thee to God's word, and thereby try all doctrine, and against this receive nothing."

These words, from a very different world, were written by **William Tyndale, the greatest early translator of the Bible into English.** But different as this world was compared to today . . . . . .

The Tradition of Hypermedia Databases

"For now as thou partly seest the falsehood of our prelates,
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Note

Tyndale, Wm. (1484-1536). English priest and religious performer, translated the New Testament into English, which aroused the concern of the Bishop of London, who in 1529 bought every copy of Tyndale's work and burned them. Tyndale was subsequently executed for his "heresy," though the authorities did him the favor of strangling him before burning him at the stake. **Eleven months later, Henry VIII, newly declared head of the English Church, authorized the English Bible.**

Figure 7. To examine a note, the reader points to and activates a phrase in boldface. A new window appears to present the associated text, which contains boldface phrases of its own.

and returns to the original paragraph.

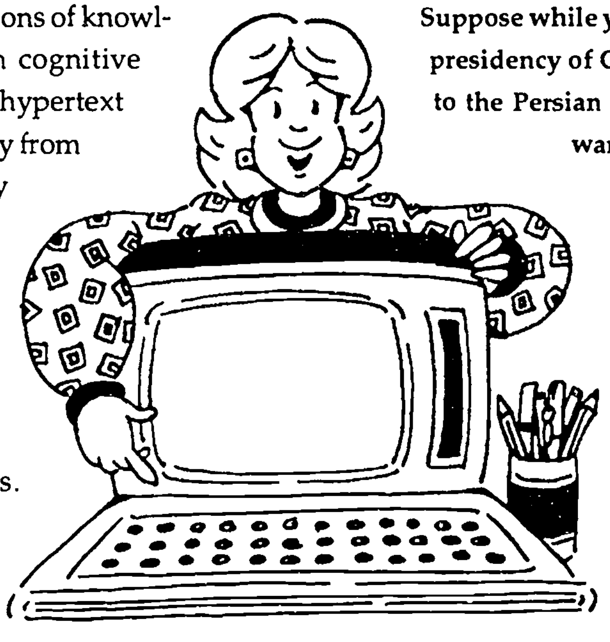
In a sense, the process is the equivalent of looking up the references at the end of each notation, or the citations at the end of the book. A major feature of hypertext is that the second window can also contain boldface phrases that in turn lead the reader to other paragraphs or graphic materials. In a printed book, it would be unacceptably pedantic to write references to references, but in hypertext, writing in layers is quite natural, and reading the layers on a good personal computer is very rapid. The reader can decide when and where to "browse" further into any particular item within the main text (Bolster, 1991).

Hypertext can be considered a model of knowledge representation, with each node comprising a concept (or schema) that is associated (linked) with other nodes in a propositional network. Within network theory, nodes are often considered to contain single words, and the links to represent relationships such as "is a" or " has a." Nodes may also contain "chunks" of text, images, and audio or video tape content. Graphically, the nodes are boxes or other simple closed curves and the links are lines, with arrows, that connect the closed curves (Jeffreson, 1990).

Once graphic representations of knowledge are organized through cognitive mapping or other versions, a hypertext model can be designed directly from it by using one of the many software programs available today (e.g., *Hypercard*, *Linkway*, or *Quest*). As far as the computer is concerned, switching cognitive maps, or "modes," is potentially almost without limits. Unlike a conventionally organized book, or research paper, hypertext has overlapping windows—like a desk with papers in a pile—where at any time one can pull out a sheet, or drawing, or graphic, then put it back kand shuffle through the pile for another.

Browsing in Hypertext

By providing information links that the learner can fetch easily, hypertext offers excellent opportunities for individualized, exploratory activities on a computer—referred to as "navigating." Information can be selected on the basis of one's interests, relevance, and information needs, as well as on personal choice regarding the pace and sequence of instruction. The reader is not constrained by the subject-matter structure or the logic implied by the author's sequence of information. Because each reader's knowledge structure is unique, based on his or her unique set of experiences and capacities, the way that each individual prefers to access, interact with, and interrelate knowledge is also distinct. Linking new information to a knowledge structure is an inherently individualistic process. Therefore, the reader is free to jump around and even alter the text in order to make it more personally meaningful (Jonassen, 1986).



Suppose while you are reading an article on the presidency of George Bush, reference is made to the Persian Gulf war. You are curious and want more information, so with a simple click of a mouse button up pops a summary of the events preceding the Iraqi invasion of Kuwait. You want to see where that country is located and some pictures of the people and how they live. You want to see a detailed map of the U.S. and coalition forces facing Iraqi military defenses. You want to listen to the in-

formed opinions of political and military leaders, and you want to watch the events of the battle on a moving graph, accompanied by a commentary on the tactics. A command allows you to look at some of the military equipment, such as tanks and aircraft. Another click of the mouse will put you "inside" of an Abrams tank or an F-15 jet aircraft homing in on a target. You also want to see the aftermath of the battle, such as burning tanks and enemy soldiers walking in waving white flags, and up it pops on the screen—and so on. (See Figure 8)

An electronic resource such as hypertext can make it possible for the average student to "play scholar" with a desktop computer. *HyperCard*, the hypermedia software developed by Macintosh in 1987, requires only a dual disk drive Macintosh SE30, a computer readily—and relatively inexpensively—available to many students and faculty on U.S. campuses. *HyperCard* (or MS-DOS *Linkway*) provides access to stacks (equivalent to files) containing cards. One card is shown on a screen at a time, but links are made rapidly so that the student can move back and forth among the various stacks. The cards are made up of fields of text, pictures or scanned graphics, and mouse-operated buttons linking each to other stacks and cards. Sound can also be linked into the system, as can digitized video images or a videodisk, though the database will then require more than a single floppy disk. At the click of a computer mouse, the hypertext user can access information that would normally take many hours to accumulate by conventional library procedures. It is also unlikely that any one library would have both print

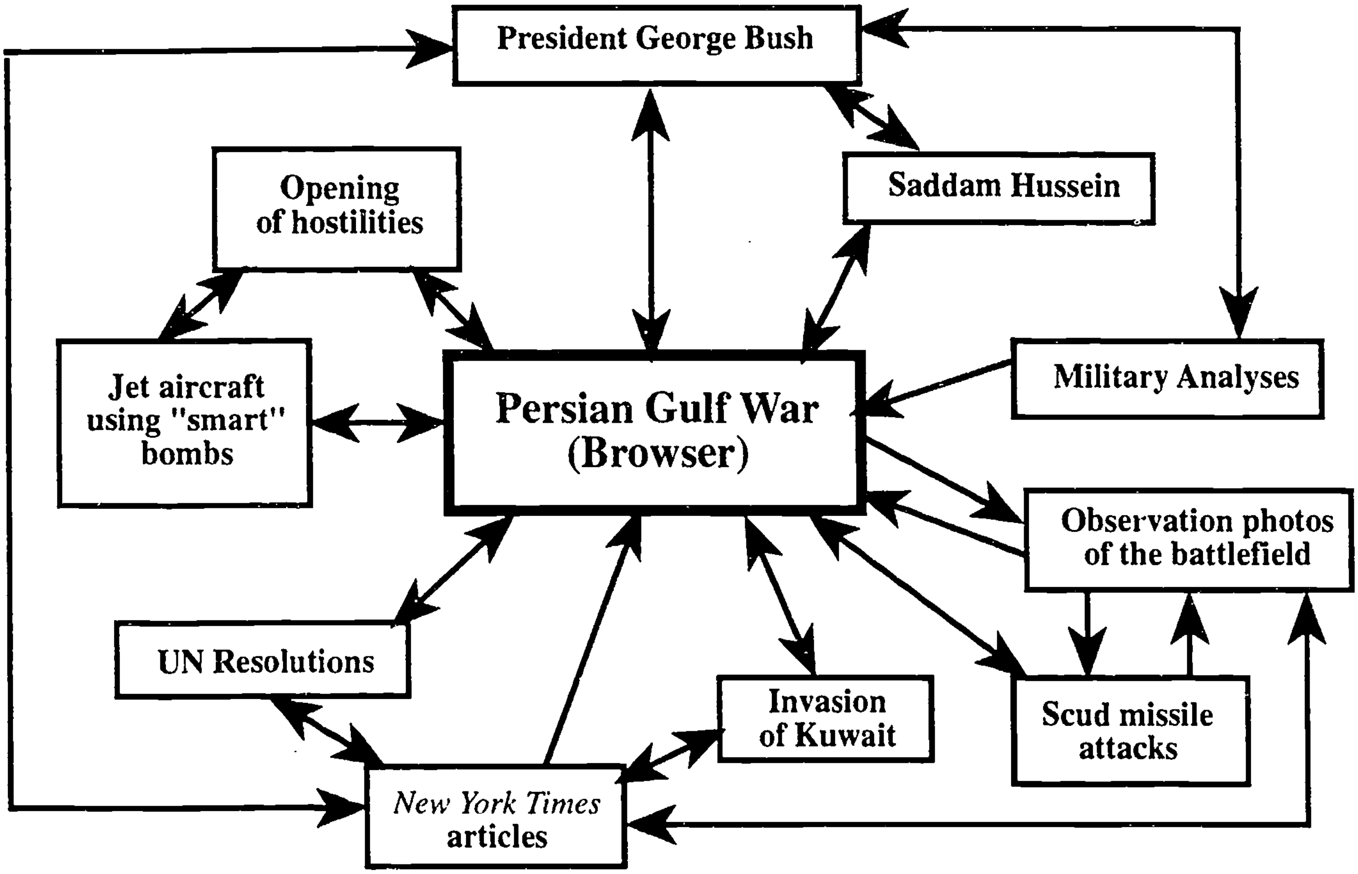


Figure 8

and visual materials at the same time.

The Design of Hypertext

The process of creating a hypertext program is similar to the act of writing. In some ways, writing is the reverse of reading. When reading, one converts linear text into a conceptual hierarchy, which is represented in long-term memory as a network of nodes and links. As we read the printed page, we pick up names, descriptions, images, ideas, and so on, which form nodes. These nodes are woven into a network that represents the theme or the major idea, as well as our existing knowledge of the subject, our attitudes, beliefs, and so on. Thus, in reading Poe's *The Masque of the Red Death*, the myriad descriptions, images, and cameo episodes all come together to create a hierarchy of horror and doom (Jeffreson, 1990).

However, creating Poe's famous short story and the act of writing is a deductive process that likely starts with the major theme: the central proposition of horror and doom. If one were to create a hypertext program, the browser retrieves information by following through the linkages of the story as far back (or as far "in") as one wants to go, in order to achieve the fullest possible understanding of the nuances of the story (see Harris & Cady, 1988).

Thus, the design of an instructional unit of hypertext begins with content, or subject-matter. The process then proceeds outward to more specfici nodes and their links with other nodes, creating a hierarchical network. From there the design proceeds to a consideration of additional information which is related to the sotry, but is not a direct part of it (see Figure 9, below).

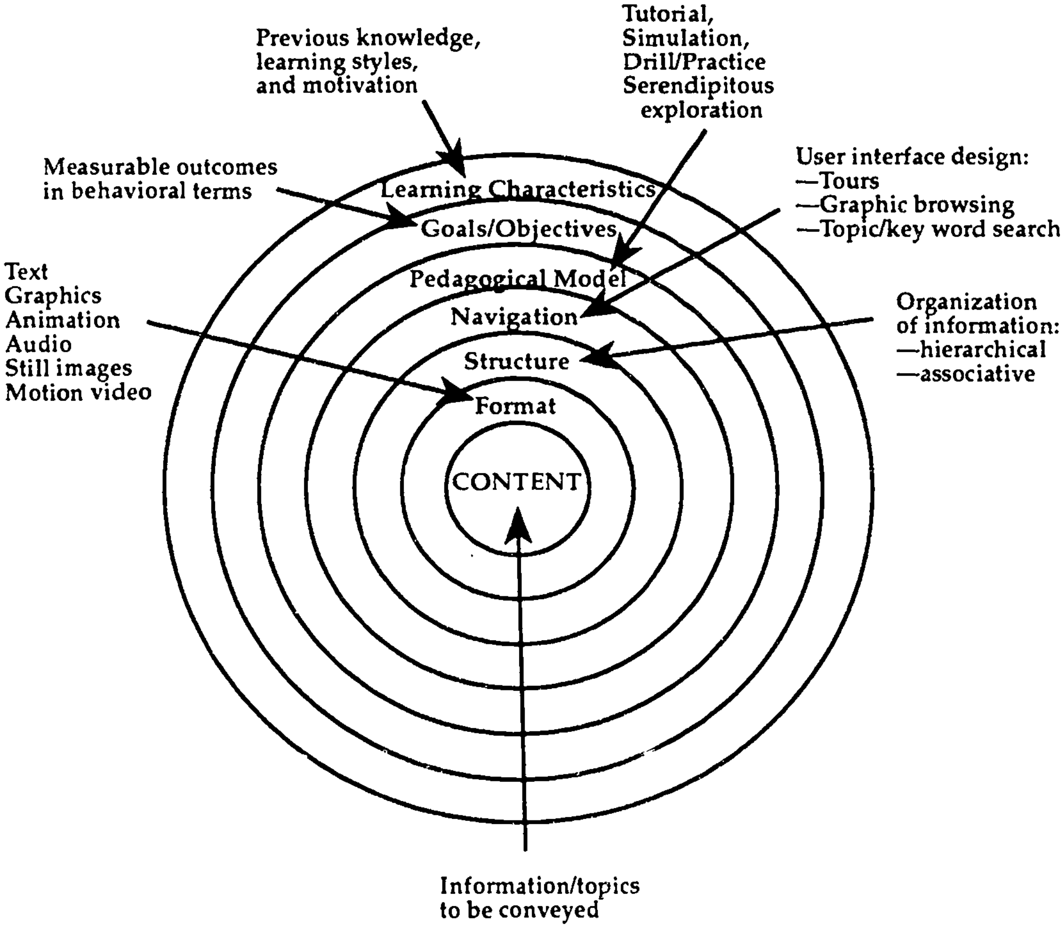


Figure 9: A Conceptual Model for Designing Hypertext
Adapted from J. Morariu, (1988)

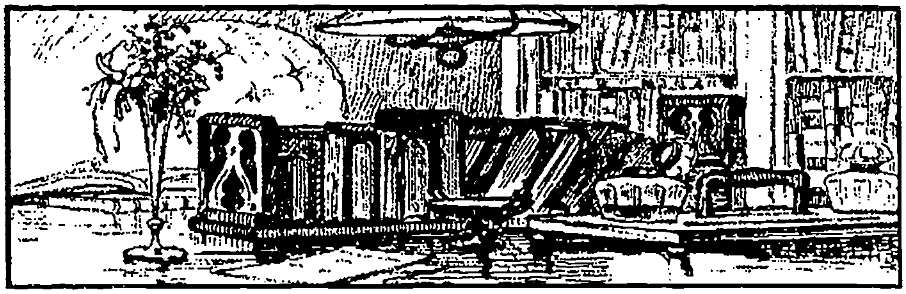
Such as a history of the author, significant influences in his/her life, and a description of the point in history of other enviromental iinfluences on the story.

But, hypertext does have disadvantages. Some believe that the unstructured nature of hypertext may be detrimental to immature learners, or those who need direction. Unassisted navigation through unstructured material may be too much for individuals who are used to a more linear approach. The less structured hypertext is, the less likely learners are to acquire new knowledge and integrate what they have learned (Marchioni, 1988, p. 14).

Balajthy (1990) is concerned about the widespread use of hypertext for slow learners, considering the poor metacognitive abilities of such students. He points out that extensive experience with hypertext in literature classes at Brown University revealed that poor or inexperienced readers were not very comfortable with linkages. He concludes that disabled readers should not have what would appear to be large amounts of unorganized information dumped on them. For them, explicit structuring of the program may be necessary in order that they understand how a computer organizes and stores information. Also, preparatory skills may be required as slow learners adjust to a non-linear, computer-based verbal environment (Balajthy, 1990)

New Cognitive Pathways

Nevertheless, just as the Gutenberg printing press initiated new ways of handling information (e.g., linear prose, cross-referencing), so hypermedia will stimulate new ways of thinking. Concepts and ideas begun in hypertext and extended by hypermedia (the utilization of the entire sensory register) will increase in density and complexity as both the hardware and software develops. Even today, the language used to describe hypermedia involves the entire visual-aural-tactile-spatial context. Collections of information are "pools," and users "navigate" through them. Content is "knowledge space," and users take "tours" through the structures. These metaphors of cognitive exploration highlight the current evolution of informat*ion* into *environment* (Carlson, 1990; Levy, 1994).



Chapter V

Problem Solving

Most human activities demand some degree of problem solving. Problems and the search for their solutions are a part of every person's life. Problems may be as specific as how to keep squirrels out of the birdfeeder or as abstract as expressing a complicated idea within the 14 lines of a sonnet. We are confronted with a problem when we encounter a situation that requires a solution, for which we don't have an immediate answer. Additionally, most individuals would add to the definition "in which the person is motivated to find a solution." In short, if a solution is easily achieved, no problem exists.

The eminent educational philosopher John Dewey (1859-1952) long ago identified this "felt need" to solve problems as a unique American characteristic. As the founder of the philosophy of pragmatism, Dewey reasoned that living and learning consisted of an endless process of confronting and solving problems, and that every human act (including the decision *not* to act) represented a choice among alternatives. Dewey and his followers held that if there were no alternatives or choices—that is to say, no problems to confront—then the individual probably will not learn (1910).

What Is Problem Solving?

A problem is considered to have four general components (Hayes, 1981; Mayer, 1983; Newell and Simon, 1972):

- **Goal, or Goals. Defining the goal of the problem is crucial to solving it. Almost any problem can be defined in several ways, and each definition is likely to lead to different attempts to solve it, called solution paths. A problem may have a well-defined goal, as in most arithmetic story problems: *Mother has one dollar in her purse. Mary asks her for 40 cents to buy ice cream from a vendor. How much does her Mother have left?* But many life problems have ill-defined goals: *What provisions do we need for a two-week canoe trip?***

- **Givens. What is available to you at the start of a problem. The one dollar and the 40 cent price of an ice cone is a well-defined given. But givens may not be specific: In planning an extensive canoe trip, what provisions are appropriate? What level of food quality do we want? Should we "rough it" with just basic fare, or eat normally? Givens may be implicit: Since cost is a factor, there is an upper limit to what can be spent for food.**

- **Obstacles: Factors that get in the way of an easy solution. The fact that many perishable and bulky**

foods must be ruled out is a constraining obstacle in the provisions problem.

- **Methods or Operations. Procedures that may be used to solve the problem. In planning a canoe trip, hard choices may have to be made: Whether to assemble the provisions item by item, thereby saving money but taking extra time and effort; or buy provisions assembled by a vendor at a greater cost but saving time and effort.**

Problem solving requires both thought and action in arriving at solutions, but it also has emotional and motivational components. Assembling provisions, specifying directions and distances, and choosing personal objectives for a canoe trip are examples of thinking components. A feeling of confidence in one's ability to solve these logistical problems represents an emotional component, and the process of packing the items in an appropriate, portable array is a behavioral component.

Problem solving is important because so much of what we learn as students as well as what we confront in daily life involves solving problems of all kinds. What we may really be dealing with here is "higher order thinking skill," that is, mental activities that should be differentiated from lesser processes, such as rote learning of vocabulary and number facts, for examples. Early philosophers such as Socrates, Aristotle, and DeCartes believed that logic was innate. While we learn from sense impressions throughout life, our ability to reason is always present b ut is improved gradually throughout life through problem solving. Socrates presented logic questions to children. When they made mistakes he kept asking them why they had made the answer they did—the "Socratic Method." Through this questioning, the students often came to realize their own mistakes without any additional information. It is geneally believed that "lower order" cognitive processes are prerequisites to "higher order" thinking. Research supports the view that excellent problem solvers tend to be very knowledgeable in their fields, but there is a dispute as to how much, and what kind of, expertise will maximize the potential for problem solving (Resnick, 1987, p. 8).

How Do We Solve Problems?

The critical question, of course, concerns the nature of the problem-solving process itself. Is problem solving a process of trial-and-error? Is it a carefully controlled movement along a solution path based on a calculated probability of success? Or does it involve sudden insight, a "light bulb" in the mind, that suddenly illuminates the correct solution path?

After students have solved a problem by their own efforts, will they retain, and transfer, what they have learned? Or will they transfer this problem-solving ability better than if they are *guided* through the steps toward a known solution?

Another consideration: If information is required for the solution of a problem, will students internalize this information more eagerly and efficiently than if the information is not associated with the specific problem solution?

Why are some individuals more effective than others in solving problems? Are they "gifted" in this respect, or have they acquired this ability by training and persistence?

Does problem-solving skill transfer from one subjectmatter to others? Are people likely to be excellent in solving problems in a subject area in which they are most interested and deeply committed, and only average in others? Behaviorists and cognitive psychologists answer these questions differently.

Behaviorism

E. L. Thorndike (1874-1949) held that problem solving was essentially a process of trial-and-error. He based his belief on the results of the following experiment: He placed hungry cats inside cages with food in full view but out of their reach. At first, the cats made only random efforts to escape the cages. They pawed, they scratched, they attempted to squeeze through openings too small even for skinny cats. Finally, by accident, they yanked a rope that opened the door to the cage. Each time Thorndike put the cats back in the cages, they took less time to get around to yanking the rope. Thorndike reasoned that their learning was incremental (improvement was gradual, coming in small bits and pieces). He further concluded that their problem solving was not directed by thinking or reasoning:

> **The cat does not look over the situation, much less think it over, and then decide what to do. It bursts out at once into the activities which instinct and experience have settled on as suitable reactions to the situation "confinement when hungry with food outside." It does not ever, in the course of its success, realize that such an act brings food and therefore decides to do it and henceforth does it immediately from decision instead of impulse** (1898, p. 45).

Later, Thorndike argued that all mammals, including humans, learn and solve problems in much the same way (1911). For Thorndike, human problem solving was similar to that of the cats, in that it is essentially trial-and-error, incremental, and proceeds without thinking or reasoning.

Early Cognitive Psychology: Gestaltism

Not surprisingly, the Gestalt view of problem solving was quite different from that of the early behaviorists. Wolfgang Kohler (1887-1967), the founder of the branch of Gestalt psychology concerned with problem solving, suggested that problems bring about a cognitive **imbalance** in us, an imbalance which creates an innate need to be resolved. Problems are puzzles that spur us into action, until the puzzles are solved and cognitive balance is achieved. Kohler also suggested that humans ponder the situation and examine all the parts of the problem, until suddenly, in a flash of insight, they see a solution. Kohler strongly disagreed with Thorndike's belief that problem solving was a trial-and-error process. He argued that there are no intermediate, incremental steps, and that problems are either solved or unsolved, with no points in between.

Kohler based his writings on a famous series of experiments he conducted with chimpanzees (1925). The animals were placed in problem situations where objects in the presence of chimpanzee, if properly used, could be employed to solve the problem. In one of these experiments, a banana was suspended from the wire roof of the cage so that it could be reached only by stacking up several of the boxes scattered on the cage floor. The purpose was to see if the apes used the materials to obtain the fruit. Apparently, the chimps fumbled around for a while, then sat back and after some minutes of looking intently at the situation, proceeded to stack several boxes and climb to the fruit.

In general, Kohler's apes behaved in ways that could be called "insightful." When they solved a problem, the solution appeared to be sudden and complete. Kohler extended his research to human beings, and he got basically the same results.

It is important to point out that Kohler believed that solutions achieved through insight are extremely "memorable." By this he meant that a solution arrived at by insight is a rewarding event. which increases the likelihood that it will be remembered and applied later to other problem situations.

Problem Solving as Information Processing

Most current beliefs regading problem solving believe that it takes more than a flash of insight to solve a problem. Attention in the field has turned to how humans acquire, store, retrieve, and then bring relevant information to bear on solutions to problems. Today's electronic computer provides a model for human thinking and problem solving. Just as the computer manipulates code in order to solve a problem, the human brain processes the large amount of sense impressions and abstract information and manipulates it in some form in order to solve problems. One of the most important elements of the entire process is the construction, according to the information processing model, is the construction of a **problem representation.**

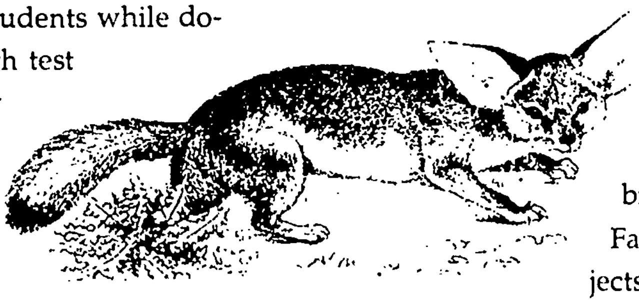
Skill in solving, for example, math problems, is directly related to understanding the nature of the problem itself (Lewis, 1989). For example, studies on logical reasoning problems such as syllogisms: *All/some A's are B's, All/Some B's are C's; if X is an A, must it be a C?*) have found that both adolescents and adults have great difficulty with such problems. If the problem is presented in abstract form or contradicts the person's beliefs, there is difficulty in one's ability to understand the problem. As a simple example, consider the following problem: MCMLI/LXI. As it is, it is virtually impossible to solve this problem. However, if we change the *representation* of the problem to 1951 divided by 61, we can apply the algorithm (long division) to solve it. It is the initial problem of correctly understanding what is being asked for, or required, that makes this problem difficult. A common obstacle with students while doing SAT or ACT math test items is the difficulty they have in understanding what the questions ask.

Solution Paths

The way in which a problem is represented determines the action that is required to solve it. In the problem representation, an **operator** is generally the action one chooses to reach the goal state. If we find ourselves at one end of the back yard and we want to get to the other end, our operator may be the act of walking. However, there may be other paths we could take to reach the goal. Paths that connect the initial state to the goal are known as **solution paths.** The total number of actions that the problem solver considers possible—whether correct or incorrect—is called the **problem space.** There may be many possible actions, however. Some restrictions may be placed on these actions by the operators. (For example, in chess, making two moves in a row is not permitted, or moving a piece that is protecting the king is permitted but will result in a checkmate and the loss of the game.)

Let's consider a situation that illustrates the information-processing view of problem representation:

> **Farmer Brown is on his way to the village market to sell some produce—a bag of corn and a goose. He has a pet fox that follows him around, so Farmer Brown lets the fox accompany him to town. Farmer Brown reaches a broad river and has to rent a boat to get across. However, it is a small, leaky boat, and it won't hold the farmer and all his possessions—it can only carry three items at a time. To complicate matters, Farmer Brown knows that if he leaves the fox alone with the goose, it will promptly eat the goose. If the goose is left with the corn, it will instantly gobble up the corn. So how to get across the river?**



Of course, the answer lies in bringing one object back each time Farmer Brown takes the other two objects across the river, but many people have trouble with this kind of problem. It is only when they realize that there are no stated restrictions about bringing an object back on the return trip can the problem be represented correctly and then solved.

Methods of Solving Problems

In the information-processing approach, problem solving consists of a search for the correct path to a solution. If there are many possible paths with wrong turns or dead ends, a problem is more difficult than if there are only a few incorrect paths. From an array of possible methods, the problem solver first has to choose the appropriate strategy, the simplest of which is called a **random search**.

Random Search Strategies

In the **random search** method, the problem solver uses trial-and-error strategies to find the solution. There are two kinds of random search: unsystematic random search and systematic random search. In an **unsystematic random search** every conceivable solution is tried. There is no attempt to be orderly in the search and no record is kept of our previous attempts. As a consequence, a response mau be repeated that has already proved to be wrong. Consider, for example, if you wanted to call a friend who lives in the same telephone area code that you do. You pick up the phone and dial at random every seven-digit number. As you can imagine, this is an extremely inefficient method, particularly because you are likely to dial some of the wrong numbers more than once.

In a **systematic random search**, all possible answers are tried, using a specified system. Assuming that you had no idea about what kinds of phone numbers are actually assigned by the phone company, you would begin with 000-0000 and move on to 000-0001 and 000-0002. This method is somewhat more efficient than an unsystematic random search, but it is still impossibly time-consuming when there are many alternative answers. At times, however, this method may be appropriate. If you are solving a jigsaw puzzle, for example, and you have two similar-looking pieces remaining, by all means try a systematic random search to see which of the two pieces fits into the space. Similarly, if you are given a three-letter anagram, YBO, with instructions to unscramble it, proceed with a systematic random search: YOB, BYO, BOY—aha! However, notice how time consuming it would be to use a systematic random search to solve a longer anagram, such as LSSTNEUIAMYOUL (Matlin, 1989).

Random search techniques, whether they are unsystematic or systematic, are examples of **algorithms.** With the development of electronic computing devices, such as the calculator, the algorithm provides a useful method to solve many problems or procedures. An algorithm is a method that will always produce a solution to a problem—sooner or later. Thus, a systematic random search of the possible letter orders in LSSTNEUIAMYOUL will eventually produce the word SIMULTANEOUSLY. Algorithms always work, even though the search for the correct one may be time-consuming and inefficient. For example, the problem of dividing 3354 by 43 can be solved using either of two procedures: (1) by applying the correct method of long division—an algorithm, or (2) by pushing the appropriate series of buttons on a hand calculator. Either way, the correct answer—78—is obtained.

Algorithms are often unsophisticated. According to Newell and Simon (1972), the intent of an algorithm is to reduce the area of the problem space in order to find a solution. The problem solver begins with a large problem space. He or she then applies relevant information about the problem in order to reduce the size of the problem space, ending up with a relatively small space to examine. For example, consider a student in a botany course who is trying to discover the name of a meadow flower by using a chart. Large areas of the chart could be eliminated right immediately by removing from the problem space those flowers that grow in deserts, swamps, and include habitats other than meadows. The problem space includes only those flowers that grow in meadows.

Heuristic Search Strategies

The teaching of algorithms is an important part of the current school curriculum, especially in science and mathematics. Unfortunately, most of the problems we face every day life do not lend themselves well to algorithmic solutions. No algorithm can establish world peace or eliminate a junk food addiction. When we can't apply an algorithm to a problem, we often use a **heuristic**. **Heuristics** are general problem-solving strategies, rules-of-thumb, and "best guesses" based on past experiences with similar problems or circumstances. d For example, the botany student who eliminates all nonmeadow flowers is conducting a heuristic search. Bear in mind that a random search procedure, such as the use of algorithms, will almost always result in a solution, although the process may take a long time. A heuristic, in contrast, does not guarantee a solution—it only offers the *probability* of a solution. For example, consider the botany student. A prankish fellow student may have transplanted a swamp flower into the meadow on the previous day. In this particular case, by using the heuristic of ignoring nonmeadow flowers, our problem solver cannot reach a solution. In summary, heuristics are less time-consuming than algorithms because the problem solver searches only a part of the problem space, and this reduction in time spent is a definite advantage. However, the trade-off is that the heuristic method is riskier—it may produce no solution at all.

Proximity Search

Proximity Search is a problem-solving strategy in which individuals make a number of moves that brings them closer and closer, by approximation, to the problem solution. Sometimes referred to as *hill climbing*, a proximity search is similar to the hot-and-cold game, where the seeker is told he or she is getting "hotter" (closer) or "colder" (farther away) in relation to the hidden object. Watch children play hot-and-cold sometime and you'll see a proximity search procedure.

A version of a hot-and-cold search can be seen in a teacher's attempts to determine the best method to teach a given unit of instruction. Small group discussion is best for some students; others benefit from conventional lecture-and-discussion; while still others are motivated by simulations and games. By trying different methods at each step of the unit, it becomes apparent which method seems to bring the best results. As in all proximity searches, the teacher may not find the ideal solution but the one that seems to work better than any of the others.

Means-ends Analysis

Another form of proximity search is known as a **means-ends analysis**, which is similar to hot-and-cold, but with an important difference. In hot-and-cold, only one method is used to get closer to the goal—for example, by varying the instructional method. In means-end analysis, choices are made from different methods (means) of approaching the goal. A means-end analysis involves breaking a problem down into component parts or subproblems and then using the appropriate means to solve each subproblem (called a reduction goal). As each subproblem is solved, the problem solver moves closer to the solution (called **apply goals**) he or she desires (Anderson, 1993).

Computer programming utilizes the means-end approach to arrive at solutions for the the many functions its program is designed to perform. Each subproblem is called a "subroutine." The computer goes by a driver which driects to each subroutine. After it it has finished, it returns to the driver. A benefit to this method, recognized by computer programers, is that if one subroutine fails, it will not "crash" the entire program. The problem subroutine can then be isolated and corrected within its smaller area of functiuon.

According to Mayer (1987a), in means-end analysis the problem solver continually asks the question: "What is my goal? What obstacles are in my way? What operators are available for overcoming these obstacles?"

A chemistry student attempting to identify an unknown substance might apply a means-end analysis. The student can use a series of reagents, a spectographic analysis, a light absorption test, or a flame test. Often these procedures are used in sequence, with successive tests made on the basis of the findings of the previous tests (Glover & Bruning, 1990, p. 198).

Pattern Matching

Pattern matching is the process of examining a problem, identifying it, and then attempting to locate a problem in one's memory of past experience that has the same pattern. In other words, problem solvers ask themselves, "Have I been in similar situations before, and can I apply the solution I learned then to the current problem?"

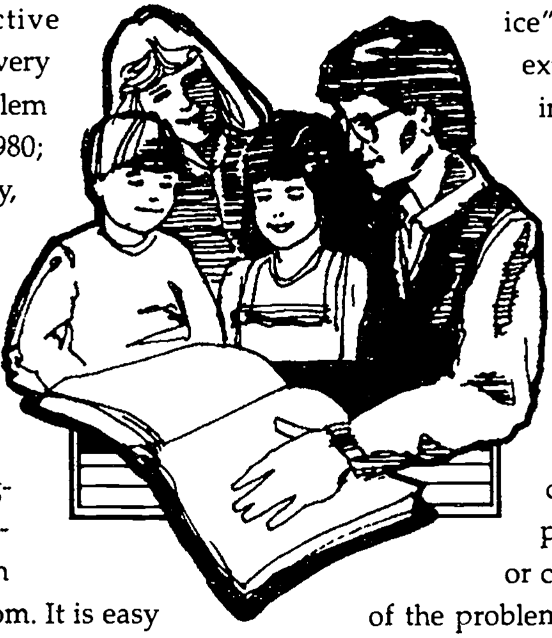
Clear examples of the pattern-matching process can be seen in the game of chess (Lesgold, 1988; Chase & Simon, 1973; Simon & Gilmartin, 1973). Simon and Gilmartin contrasted pattern-recognition abilities of novice and master chess players. They determined that a major difference between masters and novices was that masters had stored thousands of chessboard patterns in their memories, while the novices had stored relatively few. The far greater availability of recognizable patterns in the memories of chess masters presumably results in their greater ability to win at chess (1973).

Pattern-matching problem searches are also used by classroom teachers. The experiences gained in teaching, as well as in reading and advanced classwork, help teachers recognize various patterns of educational problems and their solutions. When a new problem emerges (e.g., a student who does not learn or who is disruptive), pattern matching can be one approach to finding possible solutions. In this context, case studies are useful as a means of finding answers based on previous experience.

Domain-specific Problem Solving

So far, we have been discussing general problem-solving strategies. Most of the solutions to our day-to-day problems depend on objective and systematic thinking. But if a problem is of a highly technical nature that requires knowledge of a particular subject, it may require a specialized solution. If one has good problem-solving skills, and when confronted with a specific problem—such as interpreting the recent revision of the income tax law—do these skills transfer? Can someone who is adept at solving problems in geometry also solve the problems of composing a sonnet? It is important to develop problem-solving skills that will, as much as possible, transfer to other subject-matter or situational domains.

One of the professional fields for which problem solving is a major objective is the legal profession. The lawyer is trained to confront an array of facts with which to solve complex human conflicts and problems within the requirements of the law. Before problems can be solved in a court of law, however, relevant facts have to be examined for their validity and their significance to a given situation. Lawyers may know little about such fields as physics, medicine, or psychiatry. They are trained in the logic of inquiry: to examine and evaluate facts and principles and organize them into a solution that is both logical and humane. In the process of arriving at a solution to a legal problem, the lawyer may utilize any or all of the tools of critical thinking: drawing on past knowledge or experience, making inferences, and applying thinking structures such as syllogistic reason-



ing, inferences, and inductive analysis. The lawyer comes very close to being a generalist problem solver (Morris, 1937; Harno, 1980; Stratman, 1990). Interestingly, the actual work of a lawyer will be affected by the computer. Technology is changing the profession of law, not by altering what a lawyer does when representing a client, but by changing the way that the accumulated wisdom of the profession is made available and to whom. It is easy to forsee a time when anyone with problems such as divorce, real estate sales, leases, adoption procedures, etc., will get all the legal services he/she needs from a computer monitor.

One of the major aims of education has been to impart knowledge that can be applied to problem situations other than those that are directly taught. This is called "teaching for transfer." If there are no commonalities from one problem-solving situation to another, transfer is unlikely, but if there are some common elements there can be some transfer (Baird, 1983; Bassok, 1990; Gick & Holyoak, 1980; Hayes & Simon, 1977). Knowledge about a specific area is referred to as **domain-specific knowledge.** Typically, physicists know more about the domain of physics than do most musicians, while musicians know more about the domain of music than do physicists. As we become more competent at some activity, or in the understanding of a subject domain, we develop a richer model of that domain. A basic domain model of a computer might include rote knowledge of the basic components of the computer and a dozen or so keystrokes, in order to do basic word processing. But to exploit the computer fully, one would have to develop a richer understanding of the functions of the computer. In this process, one progresses from "novice" to "expert." Not surprisingly, experts are better problem solvers in their domain than are novices. However, experts don't simply have more domain-specific knowledge—their knowledge is better organized (e.g., Chase & Simon, 1973; Dee-Lucas & Larkin, 1988; Larkin, 1985; Novick, 1988).

Surprisingly little is known concerning the potential of human problem solving. No one has made or could make any complete survey of the problems that can be solved by human beings. The ability to solve specific types of problems has been studied and made the basis of "intelligence" tests, but the validity of these tests is disputed. Isaac Newton, for example, might have scored low on such tests when he was an adolescent; yet he is estimated by some to have had a intelligence quotient (IQ) near 200. One of the shortcomings of intelligence tests is that they predict little concerning the development of a person's potential for problem solving, which is a very important skill in adult life (Jackson, 1974).

An Instructional Approach To Problem Solving

Students need to acquire information thoroughly and meaningfully. Research and common sense are in agreement that a solid knowledge base is a prerequisite for successful problem solving (Andre, 1986; Frederickson, 1984; Greeno, 1973; Norman, 1980; Simon, 1980; Simon & Hayes, 1976). Teachers often generate long lists of objectives that must be met, and as a result no single topic is covered in depth. Breadth of coverage occurs at the expense of depth of coverage and at the expense of successful problem solving and transfer of learning, as well.

- Some prerequisite skills should be "overlearned" (Frederickson, 1984). To the extent that students can process many aspects of a problem automatically and with a sense of confidence, more attention can be directed toward the more novel and difficult parts of the problem.

- Problem-solving skills are sometimes better learned through a discovery approach. Guided learning in many cases is very efficient, whereas discovery learning is probably most appropriate when problems are ill-structured and students have a solid knowledge base (Doyle, 1983; Frederickson, 1984). However, with specific, well-structured problems that can be solved by a specific algorithm (e.g., long division), direct instruction may be preferable for beginners (Frederickson, 1984; R. Gagne, 1985).

- Teaching general learning and problem-solving skills may be helpful. Many theorists believe that teaching general problem-solving strategies can be useful (Gagne, 1985; Mayer, 1987b), and it can be fun because the examples often are challenging. One helpful strategy is having students talk aloud about the problem; a second is using paper-and-pencil to map the problem or diagram its components; and a third strategy is brainstorming, which is a great opportunity for group discussions and give-and-take on a problem situation (Ormrod, 1990, p. 360).

- Finally, students need to learn strategies and attitudes for solving ill-defined problems. Most problems presented in the classroom are well-defined, and, in fact, good instructional design principles call for clear objectives and specific feedback of right or wrong. As examples of clearly defined problems, students are asked to identify the protagonist and antagonist in a story, use library facilities to locate the country of *Chad*, or calculate how many candy bars each of six girls will have if there are 24 bars altogether. On the other hand, most real-world problems are vague, such as what college major to choose, or what topic should be the subject of the senior year term paper.

Ill-defined problems often require an individual to search outside sources for relevant data. Students should therefore be well-versed in techniques for gathering information from such sources as libraries, computer data bases, and government agencies.

Above all, it is very helpful to have a positive *attitude* toward solving problems. Skillful problem solvers usually have a strong belief that persistence, combined with many different approaches will, eventually, pay off. If you assault one side of the problem and it doesn't get you on the solution path, you retreat, regroup, and try another tactic. Although we have documented, in many places in this book, that success in *general* problem solving does not predictably transfer to other settings, an attitude of confidence and persistence *does* transfer (Dudley-Marling & Owston, 1988). It is an axiom in the business world, that many individuals who got to the top of the success ladder and then experienced a precipitous slide into failure, are usually regarded by their business peers as a good bet to get back on top again. In other words, they are perceived as "winners." Good problem solvers have an *expectation* that they will find a solution, and this is what transfers from general problem-solving experience to the ill-defined, novel, and often completely unforeseen problems that occur to all of us in real life.

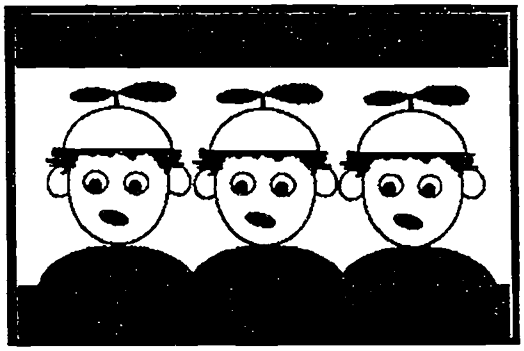
Chapter VI

Artificial Intelligence

When you play chess, you are engaging in a pure form of pattern matching (especially if you are an expert). But most of our daily problems, and academic problems as well, are not as neatly structured. The problems we have the most trouble with are usually situational, and they often require knowledge and intellectual resources beyond what most of us are able to bring to bear. The branch of cognitive science that attempts to program computers to aid in these forms of problem solving is called **artificial intelligence** (Anderson, 1993.)

In order to process, store, and retrieve data intelligently, most AI programs organize their knowledge into three areas: (1) data storage, (2) rule set, and (3) a control structure (Sayre, 1986).

The **data storage** component is much like any other computer program. It consists of all data entering the system, as well as any rules specifying the outcome of the process.



The **rule set** is the most powerful portion of the system because it comprises the storehouse of specific and general rules that can be applied to the data coming in. Each of the rules in the data sets acts as a decision maker, by matching the data being processed to other rule patterns and then making a decision. This decision may be a simple yes or no answer, or a sequence of decisions that lead to a problem diagnosis. In many cases, this pattern matching procedure is linked to others, so that it becomes part of a much larger rule set. This large base of rules is considered to be the knowledge of the system (Maxim & Yaghmai, 1984).

The **control structure**, or reference processor, is the the key element of an artificial intelligence program. It integrates the data and rules in an organized fashion, according to the needs of the particular problem. This control structure can be defined as: a library of approaches or strategies that designate which rules should be applied and at what point (Maxim &Yaghmai, 1984).

When all three of these areas are integrated properly, they will accept data pertaining to a problem, identify a pattern or relationship among the data, and select the specific rule or rule sets to be implemented in order to reach a conclusion.

With many problems that are relatively simple and familiar (such as arithmetic drill problems), we apply the appropriate algorithm. With complex problems, both inside and outside the classroom, we run into two difficulties: (1) The amount of information (i.e., stored "solution paths") relevant to a solution is often too great to keep track of mentally, and (2) there is a good chance that we simply do not have all of the information to begin with. The computer can provide the back-up experience, or knowledge, required for complex problem solving and can simulate, or mimic human thought processes in utilizing these data. For example, the most successful computer program for chess is able to evaluate as many potential moves as possible, in as little time as possible. The program that can call up the largest number of moves is more likely to win the game.

A dramatic application of artificial intelligence is an example from the medical profession: MYCIN, a program that simulates a physician specializing in infectious diseases. The computer program contains a series of clinical rules which will allow it to diagnose a given syndrome and prescribe an appropriate treatment.

> The rules follow an "IF . . . THEN . . . " procedure:
>
> IF . . .
> (1) The site of the culture is blood,
> (2) the gram stain of the organism is gramneg,
> (3) the morphology of the organism is rod, and
> (4) the patient is a compromised host,
> THEN . . .
> There is suggestive evidence (0.6) that the identity of the organism is pseudomonas aeruginosa.

The program can be written so as to answer questions and provide additional background data. MYCIN and similar computer-based medical programs are often as accurate, and sometimes even more accurate, than medical experts. MYCIN-type programs are especially valuable for the diagnosis of rare diseases. With the rise of global travel, people often unwittingly carry back to their hometown rare diseases, which may be outside the experience of local physicians. With the aid of a computer, physicians who practice even in the most remote areas can access a medical data center for a diagnosis with a strong probability of accuracy, as well as get additional background information on the disease.

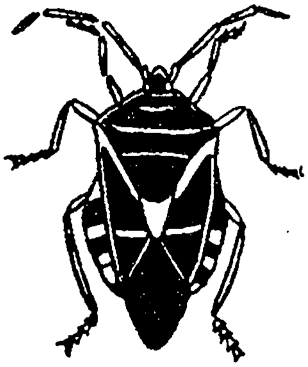
Computer simulations are another example of artificial intelligence. A simulation program is a model of some part of the world that is obviously beyond the environment of the classroom, or is set in the past or the very distant future. Simulations afford a powerful tool for teaching problem solving in historical, complex, or often abstract settings (Woodward *et al*, 1988; Okey & Oliver, 1987). Simulations can be designed to teach procedural skills—for example, to provide student teachers with practical experience in diagnosing and remedying children's reading problems or managing teaching strategies in mathematics, before working with real children. Students can be evaluated on how quickly and accurately they arrive at a diagnosis, or they can be evaluated on the variety and originality of simulated solutions to a classroom problem.

Such basic human behaviors as touching, smelling, hearing, and seeing are the result of eons of evolutionary development. The origins of these behaviors lie deep in our physiology, and we don't understand very well how they work. These are processes we have in common with the animal world. The thought patterns that differentiate us from the animals, however, are quite new. They are at the top of our thinking mechanisms. Thinking processes needed for such subjects as mathematics, science, literature, and logic are relatively recent acquisitions. It is these that artificial intelligence handles the easiest. For example, logic is a human invention, but it is really "artificial"—it is not a natural product of human evolution. The computer can be programmed to solve complex, logical problems, such as the probability of a tornado occurring, based on scores of variables. Ironically, it is very difficult to program a computer to do simple tasks, such as create a flower arrangement in a vase.

'Buggy' Models

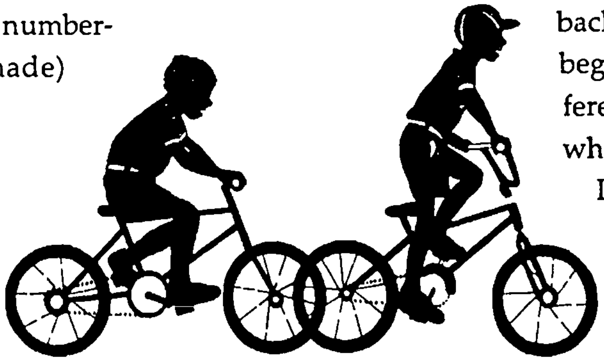
One of the most fascinating developments from research on artificial intelligence is the notion of **buggy models**, from the term "debugging," which refers to the process of finding the program or system errors that cause a computer system to "crash."

In practice, you let the computer run, and when it crashes, remove the offending little piece of code ("bug"). In teaching problem solving, debugging means highlighting, and then removing, students' errors in thinking. With sophisticated programs, the task is not a simple one. Complex programs require that one not only locate the "bug," but restructure the knowledge (data and procedures) in the program to make it behave properly.



The so-called "buggy model" is a new element in the analyses of problem solving. Early psychologists and educators were quite aware that children's errors tend to be systematic, but educators concentrated on identifying the most common errors among groups of children. Errors were regarded as fuzzy thinking, although learners sometimes go down incorrect solution paths that may have a logical structure of their own. Several intensive investigations have produced models of problem solving in which errors are characterized not by missing knowledge or facts, but by the imaginative creation of new rules, "buggy rules," as they are called (Brown & Burton, 1978; Sleeman, 1982; Resnick & Omanson, 1987).

In addition, students do make careless slips, and it is important to ensure that these do not deflect the problem-solver unduly. A buggy model assumes if the student's error is within a certain tolerance, that the error is a number-fact-retrieval problem and should be ignored (i.e., one should respond to it as if the correct number-fact-retrieval had been made) (Sleeman, 1984).



Error Library

Computer programs can be designed to help students look at their errors and analyze the thought patterns that led to those incorrect solution paths. A highly interactive program allows the learner to "tiptoe" through his or her knowledge structures, and the program then allows the learner to re-enact the process and make decisions on what to revise. It is possible to compute which errors (or combinations of errors) best accounts for the incorrect answers of that student. Called an **error library**, it provides a database for learner-controlled remediation. Debugging, then, is a form of cognitive *self-regulation*, since being able to examine clearly the decisions one made becomes a scaffold for further exploration and restructuring (Psotka, 1985; Duemler & Mayer, 1988).

Also, the buggy model can provide an environment for *self-reflection*. All of us at one time another have retraced in our minds the course of an argument, or a conversation with someone and realized errors or shortcomings in our logic. We might say, "Now, whatever possessed me to make that statement?" or, "I don't know why I did that; I should have done something else!" Reflecting on past errors, if we are able to look at all the aspects of that problem objectively, can be educational. A computer program can take one back through an entire procedure, utilizing rules or heuristics for comparing the present state of knowledge with the past, so that the procedure can be modified. For example, we can learn from falling off a bicycle something about how *not* to maintain balance. You could backtrack to the point where falling began and then try to do things differently: e.g., "Perhaps I turned the wheel too sharply. Maybe next time I should shift my weight to counterbalance . . etc." Sophisticated simulation programs with built-in buggy models (Norman, 1981; Psotka, 1985), may provide the means to understand, objectively and nonpunitively, the error mechanisms in our own thinking processes. A computer program called IDEBUGGY, for example, categorizes a student's incorrect procedures for calculating subtraction problems according to a dictionary of previously defined mistakes or "bugs." Knowing which bug characterizes a student's approach to subtraction problems provides the basis for IDEBUGGY's selection of the type of problems it will pose next (Winne, 1989).

Brown and Vanlehn (1982) identified faulty strategies or "bugs" children use in subtraction problems. For example, in solving simple computation problems such as 24 plus 13, first-graders learn that they can start with the bottom number in the units column or with the top number: 4 plus 3 equals 7, and so does 3 plus 4. The similarity they note is that these problems can be worked in either direction, from top to bottom or the reverse. Then come subtraction problems such as 24 minus 13. Students may still apply the similarity learned in addition, thinking of the difference between 4 and 3 or between 3 and 4, and always subtracting the smaller number from the larger. However, when students encounter a problem such as 74 minus 15, applying the similarity noted earlier could lead them to subtract the smaller from the larger number and come up with the incorrect answer 61. Such a mistake is a sensible application of a incorrect rule. Knowledge of these strategies can help the teacher to understand the repeated errors that children make, and provide instruction that goes beyond simply giving positive or negative feedback for each problem (1982; Carnine, 1990).

Behaviorists Believe In 'Error-free Learning'

Behaviorists have always maintained that learning should be "error-free." Or, putting it another way, behaviorists don't think we learn very much from our mistakes, except a determination to avoid them in the future. This attitude assumes that what has been made is a clear and specific, though incorrect, response. Most of the important problems we have to solve are ill-defined, and they usually require some tentative probes before the correct solution path is found. In fact, in many cases a "wrong" solution could generate a new set of rules, or a new way of structuring both the problem and the solution. Buggy-modeled computer programs allow the learner to "play around" with errors, to introspect, so to speak, on the value of choosing a particular solution path from many alternatives. In addition, teachers often are reluctant to discuss publicly a child's error, thinking it might cause the child embarrassment and discouragement. The net effect is that, although good explanations of correct, algorithmic procedures are offered to children, the explanations are usually not tied to the specific occasion when children are most likely to make errors. It is precisely at those moments when an understanding of the "buggy" action is most useful. An interactive computer has both the knowledge and diagnostic capability to respond when it can do the most good.

The Development of Expertise

The course of knowledge acquisition usually begins with general knowledge, which foreshadows the application of that knowledge. At first, the learner may "know" a principle, a rule, or a specialized vocabulary term without yet knowing the situations where it applies and how it can be used effectively. Beginners tend to have the requisite knowledge, but are less able than experts to know what to do with the knowledge. When knowledge is accessed by experts, however, it is usually understood by these experts as to how and when it can be used appropriately. Experts and novices may be equally competent at recalling specific items of information, but experts are better able to associate these items in memory in relation to the solutions and substeps of specific problems, procedures, and end-performances.

Another characteristic of experts is their complex knowledge structures (schemata), which help them to match features of the current problem with those of previous ones to retrieve problem solutions. Given a particular problem, experts have rich representations, or **mental models**, which assist in the identification of potential solution path(s). Novices, on the other hand, appear to stall out and lapse into one of two dysfunctional responses. Either they have only a meagre notion of what to do and settle on a simplistic, often superficial solution, or they have no plan of operation—overwhelmed by perceived difficulties, they give up!

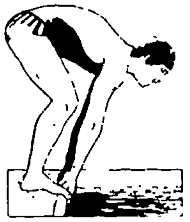
Expert Performers

As has been mentioned before, the examination of performance differences between experts and novices has become a topic of considerable interest. Some of the various skill areas and that have been explored include, among others, chess, the social sciences, and athletics (Phye, 1986).

Benjamin Bloom (1986) published the results of a 3-year study of "experts." The subjects in this study were world-class Olympic swimmers, pianists, and research mathematicians. All these individuals had attained "world-class" status by the age of 35, and the typical individual began learning at a very early age. The subjects appeared to have three characteristics in common. These were: (1) a strong motivation to practice, (2) a strong will to succeed, or win, and (3) the ability to rapidly learn new techniques, ideas, or strategies in the talent field.

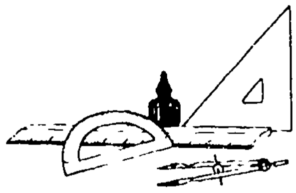
The result of years of diligent practice is what Bloom calls automacity—the capacity to perform and act almost without conscious attention. According to Bloom, once a skill has been developed to a high level of automacity, it requires frequent use but very little special practice to maintain at that level. Having achieved this level of performance, other conscious brain functions will occur during the automatic functions, such as thinking about improvements and innovations in performance. Bloom believes that it is important that *all* students achieve mastery levels in both declarative and procedural knowledge, especially in those particular processes and skills that are prerequisite for later learning (1986).

In addition, everyone who achieves a high level of performance in any field invests a deal of time. Hayes (1985) estimated that it takes 10 years to achieve an expert's level of performance in most professional fields. This indicates that expertise comes not from superior problem-solving ability, but rather from learning more and more about a given field, or domain.



Expert Systems

The concept of mental models is similar to **expert systems**, which are computer-based consulting programs that are capable of bringing information and decision-making support to the solution of a problem in a specified field of study. Expert



human problem solvers have tremendous advantages over computers, such as flexibility, broad experiences, and innovative insight. But they require knowledge of the subjectmatter domain, and this can take years to accumulate. Books are used by human experts as refeences for knowledge and applications. Written communication is easily disseminated and stored, and it is either free or available for a minimal cost through a system of libraries. But the retrieval of knowledge in this form inefficient and labor-intensive:

Although books store the largest volume of knowledge, they merely retain symbols in a passive form. Before the knowledge can be applied, a human must retrieve it, interpret it, and decide how to use it to solve problems (Hayes-Roth et al, 1983, p. 287).

Computer-based, expert systems have the potential to reduce the knowledge retrieval process so that problem solving can focus on solution paths. Computer-based systems can bring problem solving closer to every learner—not just those who have acquired a lot of knowledge or have a lot of experience in the subject area. Perhaps nothing can take the place of human experience and insight with respect to most problems, but computer technology has the potential to allow almost everyone to be an "expert" in some problem-solving areas. Young, inexperienced learners could be spared a lot of time with conventional, textbook situations, and will be empowered to focus on real, or quite important simulated problems (Nelson, 1989).

Chapter VII

The Electronic Classroom

The Human Quest for Empowerment

Since the beginning of society, humans have almost always turned to teachers for instruction and guidance. As the knowledge base expanded, so also did educational institutions and the profession of teaching, both of which were essential in passing on the new knowledge to succeeding generations. Yet, the "self-made man" was a revered ideal, the individual who acquired knowledge and wisdom by himself or herself. He, or she, was a "Renaissance" person, an intrinsically curious and searching individual with a desire to learn and understand. Today, we might describe the Renaissance person as one who is truly empowered—he or she has "learned how to learn." In broader, perhaps more mystical terms, it is one who is intellectually free and self-actualized. Our best example is Abraham Lincoln, who managed to get only about two years of formal education—by "littles," as he put it—but he was a self-directed learner all of his life.

However, the quest for knowledge was not always happily condoned by society:

> **Forasmuch now as thou partly seest the falsehood of our prelates, how all their study is to deceive us and to keep us in darkness, to sit as gods in our consciences, and handle us at their pleasure, and to lead us whither they lust; therefore I read thee, get thee to God's word, and thereby try all doctrine, and against this receive nothing.** (William Tyndale, *The Obedience of a Christian Man)*

These words were uttered by William Tyndale, who in the 16th century translated the Bible into English (and was burned at the stake for it). In his day few people could read the Latin Vulgate Bible, so most people had to depend on trained priests to interpret the Scriptures for them. The authorities considered Tyndale's work subversive (which it was), and they put him to death eleven years after he published his translation of the Bible. His life ended only eleven months before Henry VIII, newly proclaimed head of the English Church, authorized the English Bible. Now, the common people no longer had to depend on religious authorities for enlightenment. The reverence for authority traditionally reserved for the Church was now directed toward scholars of all intellectual callings. This was a step toward emancipation from Church dogma, since scholars disagreed with each other and individual reason was required to choose among them. With the proliferation of books printed in the vernacular on Gutenberg's printing press (which was the information technology of that day), all who could read now had the power to acquire knowledge and to think for themselves (Crane, 1990). What is more, the proliferation of books encouraged private reading as opposed to public reading or the oral tradition. Communication could occur without the social interaction of members of society. Such communication in seclusion encouraged a new sort of individualism that is probably one of the most important differences between traditional and modern societies (Clabaugh & Rozycki, 1990, p. 326).

From Writing to Speaking and Viewing

The written word is one of the recent achievements of human beings. For 10,000 years, humans learned from gestures, images, and speech, but for the last 500 years, humans have learned primarily from print. The first form of writing was executed by means of gestures, and this "drawing in the air" came immediately prior to the development of *pictographs*, or graphic language. Pictographs bore considerable likeness to the object portrayed, such as a circle with lines emanating outward to depict the sun. Over time, conventional signs evolved to the symbolic and away from the strictly pictorial. Our Western Heritage of thought and culture evolved from the legacy of early pictographs to a highly complex, written language system. Until the invention of writing there was no effective way of preserving and passing on achievements to succeeding generations. Certainly, early communication was quite rudimentary when compared with the language that we know today—the legacy of Milton, Shakespeare, and the Bible.

Stroud (1956) cites Coulton on the level of thought of medieval times:

> **Think what the mind of the villager in medieval England must have been like. His average vocabulary was not more than a few hundred words. Perhaps all except the priests were illiterate. The villages were separated by vast forests, sources of both fear and danger. Few roads connected village with village; many persons never traveled beyond their own in their whole lives. They knew but few people. A peddler, a wandering friar, or a mason if a church needed repair, brought in such news of the outside world as the village received. The mental horizons of the people must have been limited to an appalling degree (p. 205).**

By the 20th century, the grammar and syntax of the written language had become the cultural standard not only for writing but for speaking. If one reads the speeches of Abraham Lincoln, we are struck by the formality of his prose, the carefully crafted sentence structure and syntax. In Lincoln's day, in order to achieve status and power in human affairs one had to discard vernacular speech habits and master formal, oral discourse based on the standards of the written language.

Today, the trend is to the opposite. The spoken language is becoming the standard; increasingly, we write the way we talk, and it started with America's favorite writer—Mark Twain. Novels of the 19th century and prior contained narration, but not *vernacular.* Mark Twain's decision to adopt Huck Finn as the narrator of the tale of *Huckleberry Finn* in the vernacular had important implications for literature (Emerson, 1984). This permitted Twain to not only present a story in the exact words of its chief character, it provided a vehicle for the writer to express attitudes of irreverence, skepticism, and outspokenness (with the consequence that the book when published offended many genteel readers). This was a significant step in the evolution of literature: it made the written word sound like the spoken word. Mark Twain was quite conscious of what he was doing. In a previous essay, he had railed against the literary conventions of the time, the artificial dialogue of esteemed writers. In a diatribe against James Fenimore Cooper, Twain wrote:

> **When a person has a poor ear for words, the result is a literary flatting and sharping; you perceive what he intended to say, but you also per-**

> **ceive that he doesn't *say* it. This is Cooper. He was not a word-musician. His ear was satisfied with the *approximate* word (1906, p. 95).**

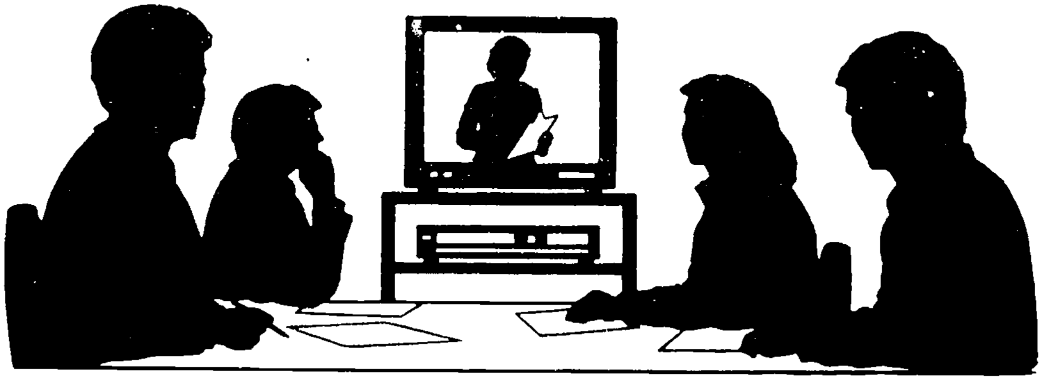
In Huckleberry Finn, Mark Twain makes extensive use of a technique that is common in fiction writing today: telling not so much what happens as what was experienced, by the ear, the eye, all the senses. It popularized oral communication.

The teaching of English has moved away from a formal prose structure to a looser, vernacular-based standard for both writing and speaking. In the 19th Century, there was a bias against the use of the vernacular in speaking (including the use of profanity), as there still is in England today. Formal, Latin grammar was associated with middle- and upper-social classes. Today, the teaching of both writing and speaking writing is no longer based heavily on classical prose forms, but focuses instead on communicating in "plain English." In teaching writing, English teachers try to activate the writing process by having students talk about the experiences of their own lives. But in so doing, students tend to avoid the more complex—and interesting—forms of grammar and syntax, thereby getting around usage errors such as *lie* for *lay*, or *that*, for *who* or *whom* (Christensen, 1990; Mazer, 1990). One authority in English education predicts that "a new kind of hybrid, written and graphic and perhaps even spoken, may come to replace, in part, the kind of expository essay we now require of writing subjects" (Gallagher, 1988).

Government agencies, businesses, and the legal profession have begun to revise their publications and to write in "plain English," going from formal, prose forms to communication that sounds the way we would say it (Dorney, 1988). Many writers use dictation as a way of inducing written text.

The Emergence of the Visual-oral Environment

The Information Age was already here when the Apple II+ first made its appearance in schoolrooms all over the nation in the early 1980's. The instantaneous transmission of television sound and images by means of satellite relay had already shrunk the world community. Today, computerized electronic technology is making possible not only the broad and rapid distribution of information, but its manipulation, analysis, synthesis, and recombinations as well. Much of this new knowledge is, and will continue to be, expressed in printed language, but an increasing proportion of information is being produced in other forms: images—still and moving, graphic and photographics; sounds—natural and synthesized; and symbolic representations of all kinds including icons, graphs, and concept maps. Behind the tech-



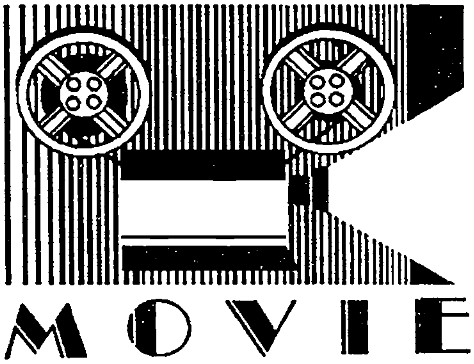
nology, a pervasive, world-wide change in the nature of communication itself is underway.

The shift from *print* as the major medium of communication to a combination of *visual-oral* expression is being propelled by the mass media. Whether we welcome it or not, the amount of time that Americans spend looking at talking images on television is increasing. Furthermore, the informational value of the electronic media seems to be as important and may become even more important than its entertainment value. As a cognitive process, this phenomenon can be described as a movement from linear (print) to non-linear (oral-visual) forms of communication.

The trend from formal rhetoric to communication conveyed largely to eye and ear is reflected in the history of moving pictures. Early black-and-white films (influenced by the legitimate theatre), frequently contained long speeches, a characteristic of most of the stage plays of that era. In today's movies, however, the characters usually speak no more than three or four complete sentences at a time. Most movies, in fact, are "scripted" for action and visual impact, rather than rhetoric. The legitimate theatre, too, is evolving toward short, snappier productions. Most plays produced today have two acts that run no longer than two hours of playing time, and some run for an hour-and-a-half without an intermission. Audiences won't sit through long, dramatic orations. (The 3-hour plays of George Bernard Shaw would never get beyond a studio production.)

Youth of today are reading somewhat, but not as much as the generation before them, because reading and TV compete with each other. This fact is already evident in the comparisons of the number of hours that children spend watching television and the amount of time reading. Young people today are "two-channel learners"—one channel is what they learn at school, and the other channel is what they learn from the entertainment industry. The educational establishment is fond of blaming the distractions of audio-visual media, mostly television, for the supposed decline or lack of progress in literacy. Neil Postman, for example, argues that the habit of watching television quite literally scrambles our capacity for rational discourse, and with it our capacity to read cogently. He objects to the ascendancy of *visual* discourse over *literary* discourse (1983; 1992). But the evolution from print to visual has been underway for over a hundred years, and it is accelerating. It would, of course, be sad to think that future generations will be less inclined to avail themselves of our rich cultural history in print—old history and old literature. But if we look at the way most people get their information about the world now—from television, movies, radio, and telephone—it may be unrealistic to believe that they will always retrieve past glories by reading

A significant effect of the onset of the visual-oral environment may be the building up of a common, cultural heritage based not on the printed word of the past, but on electronic images. If a society shares a cultural heritage that is no longer derived from the written language, but is conveyed by current electronic imagery, that image heritage will lack the history of that society, its historical and cultural traditions, its shared values based on the past. It may be a common heritage derived from movies, TV programs, TV news bytes of the world, videotapes—all those images stored in memory, but comprising a randomly organized "database" for contemporary values and behavior. No longer can we assume that today's youth will share their parents' knowledge of the same written literature or of history. Instead, young people may store those images that they have actually experienced, largely through the senses, which means that this generation could have a sense of history that goes back barely a decade.



Not only do the media create and control the climate in which education is perceived, but also they represent, in both content and form, a *new education*. For example, it is no longer possible to consider the political process in this country without first understanding television's impact on it. Also, it is no longer possible to examine the major health issues of today without recognizing the role that the media play in creating them and the role they can play in combating them (Considine, 1990).

Visual Literacy

Visual literacy is both a concept and an educational movement. The term, visual literacy, can be defined as ". . . the ability to understand and use images, including the ability to think, learn, and express oneself in terms of images" (Braden & Hortin, 1982, p. 41). It is clear that humans are able—somehow—to store images in their memory, as well as words, and to recall them as images and as words. But is learning from images different from the way we learn from print? Quite possibly. Humans appear to be able to hold an image in short-term memory and move it around in fairly complex ways, thereby creating a visually-organized schema for long-term storage that is not verbally or procedurally encapsulated. Researchers are studying the cortical visual area of the human brain to determine how distinct visual stimulation is from verbal information process, but the research is very tentative (Farah, 1988).

Schools may have to teach this generation of young learners how to understand images, just as once we felt it essential to teach young people how to read print. Teachers, too, will need to study the impact of images, and how much and what kind of print will have a maximum effect on the viewers. Above all, we need to accept the reality of the electronic class and what it could mean to schools of the future:

> **Electronic imagery may change the way in which we define problems and create solutions. As it becomes possible to form images of problems, rather than seeing them spelled out in linear form, we may be able to hold more complex relationships in an image and to see the interactivity of one image with another . . . . It is possible that imagery thinking may be a critically important tool for looking at a world that has become too complex, too intertwined, for linear information to handle or comprehend (White, 1987, pp. 59-60).**

The visual medium and the written language are different; they serve different purposes. Film presents provocative and illustrative images, but print is considered to be necessary for thoughtful analysis. Beginning with Comenius, who advocated pictures and graphic materials to enhance textbooks, visual content has become a major feature of most textbooks—especially those for children. The technology exists today that takes the next step: knowledge presented visually with print included for details and elaboration (White, 1991; Bracey, 1992).

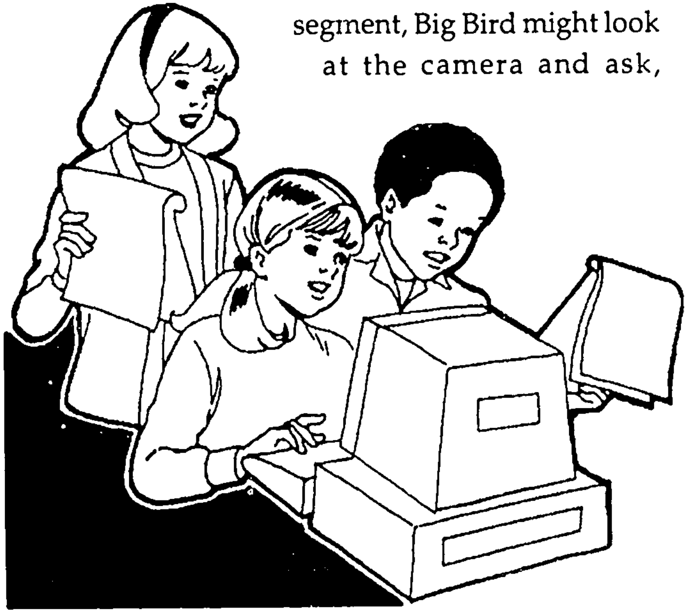
The Electronic Classroom

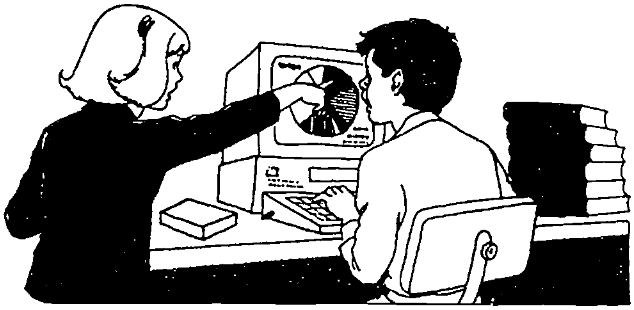
Sesame Street

The first electronic classroom was *Sesame Street*, the creation of the Children's Television Workshop (CTW) in 1968. After 25 years, *Sesame Street* continues to be an electronic experiment designed to prepare preschool children—especially poor, inner-city children—for school. It is the result of cooperative expertise in media production, educational curriculum, children, and behavioral and cognitive psychology. The intent of *Sesame Street* is to be seriously educational and entertaining at the same time. It has had worldwide success, with licensed versions, adaptations, and coproductions of Sesame *Street* seen in approximately 115 countries (Gettas, 1990).

What accounts for *Sesame Street's* unprecedented popularity, both in the U.S. and abroad? The key factor is its broad appeal to children. Children like *Sesame Street's* humor, tempo, characters, stories, and songs. They like its muppets and its fast-paced format. It is an educational medium that speaks to them in their own language, on their level, and with respect for their intelligence.

But *Sesame Street* is not truly an *interactive* medium. It is one-way, and it sends the same electronic signals to everyone on an unchanging schedule. It can become interactive only in the home, if parents and others discuss the programs with the children. To a limited extent, however, the producers have created some degree of interactivity. For example, in a typical interactive *Sesame Street* segment, Big Bird might look at the camera and ask, "Which one of these shapes is a square? Point to the one that's a square." With an encouraging word or a "prompt" from a parent, the child viewing the segment is likely to point at the square. The next major step—pressing a computer key, or exerting finger pressure against the monitor screen at the right place—will make the medium truly interactive. At the Children's Television Workshop research laboratory, interactive computer software is being developed that will complement the programming on *Sesame Street*. For example, *Sesame Street First Writer* is a word processor for preschoolers. It is a simplified text editor that can be used by an adult along with a small child just learning about letters, words, and writing. The child can type in words, edit the words and sentences, and scroll through the pages for review and revision. Throughout the program, icons of *Sesame Street* characters provide friendly guidance and feedback to the user, depending on his or her responses (Strommen, 1990).

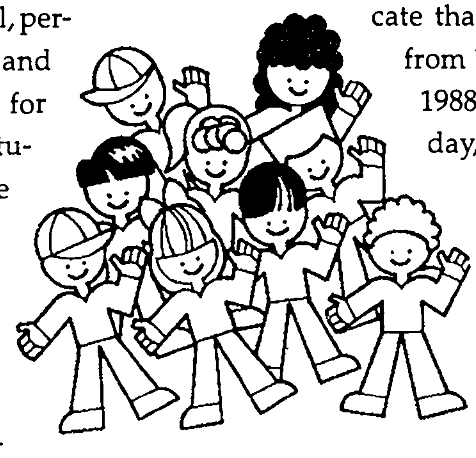




Sesame Street was the first large-scale experiment in electronic education. It happened because the medium of television existed and was becoming a fixture in almost every home—whether rich or poor. From a one-way medium, the evolution of interactive video and computer technology leads to highly intelligent tutoring systems—the ultimate empowerment for learners. Like Tyndale's translation of the Bible, which common people could now own and carry with them, electronic technologies will eventually be accessible to everyone—within or outside of formal education. As they become cheaper, electronic technologies have the potential to become the private tutors of a new Renaissance, transcending the constraints imposed by socioeconomic and ethnic factors which, as research indicates, seem to play such an important and often detrimental part in the education of our young people. It could have another benefit as well: a union of work and play. If students of all ages *enjoy* learning mathematics or performing scientific experiments on a computerized tutor, they are likely to continue without the necessity for close supervision and become life-long learners.

The Individualization of Instruction

Computer-based, intelligent tutoring systems hold the promise of individualizing instruction on a scale not seen since the emergence of the printed book itself. Eventually, schools will be designed around new, computer-based technologies. They will be equipped with an individual, personal computer for each student, and possibly an interactive videodisk for every two to four students. Most students will have a computer at home and be able to access the school's system and other data-bases at any time. Eventually, because of these new technologies, the design of instruction and even the physical layout of schools may be unrecognizable to us, may be changed in ways we can hardly imagine today.



Individualized instruction is associated with the tailoring of instruction to such characteristics of the student as entering behavior, learning style, and most often, learning rate, in recognition of the fact that different learners need different instruction. These design characteristics are usually difficult to implement in group instruction, and one-on-one, teacher-student instruction is not economically feasible. Computer-based, intelligent tutoring systems have the capability to adapt to the student *dynamically*, during on-going instruction, at each moment providing the kind of instruction most beneficial to the student at that time. In addition, the computer can be programmed to adapt both the *content* of the instruction and the *format* for delivering it. The computer can be programmed to generate a specific sequence of question, explanation, example, practice problem, illustration, or demonstration which will be most helpful to the learner.

The advent of intelligent tutoring systems, in economic terms, could turn the educational environment into a *learner's market*. Schools and teachers may no longer have an exclusive franchise to teach the young. The technology of instruction will provide the power to bypass the classroom and the campus. In fact, parents today are opting to teach their children at home in ever-greater numbers. U.S. Department of Education data indicate that home schools have increased from 15,000 in 1970 to over 250,000 in 1988 (Lines, 1987; Martin, 1988). Today, every state allows home schooling in some form, with varying levels of regulation (Mueller & Brunetti, 1989). The availability of computer-based technology will create an even more compelling alternative to public education. Whether educators agree with this trend or not, conventional classroom instruction will face a formidable competitor in computer-based, individualized instructional technology.

The Impact of Instructional Technology

The electronic media will not supplant print technology. Both are vital means of learning, possessing different strengths and performing different functions. The danger lies in the devaluing of print materials. If children can choose between playing "Space Invaders" and reading a book, how many will read a book? Without question, the visual-oral environment will change the nature of communication. Some decry the loss of classical forms of written expression, and some lament the trend toward mass communication via electronic images and sound bytes (Postman, 1983; Trotta, 1991). But it is a reality for education and for the instructional designer. What will be the quality of teaching and learning in a future of communication by images? At the present, we can judge only by comparison with the standards of the past, with people who were educated by a print medium. Perhaps knowledge acquired by visual-oral means will be understood neither "better" nor "worse," but *differently*. It represents the latest step in a long progression of technology in communication. The alphabet provided intellectual means of recording, preserving, and transmitting the knowledge of humanity. The invention of paper and the development of writing instruments accelerated the process of recording knowledge with alphabetic symbols. Movable type made it possible to place the written word within reach of the common people. The blackboard was one of the first joint communication devices that permitted teacher and student to view the same flexible referent at the same time. The school bus influenced the way pupils were organized for learning even in the most isolated areas. Technology could make an ordinary person capable of superior performance and become the means, whether printed or electronic, to disseminate knowledge in a global classroom.

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