Cognitive Psychology and Educational Practice

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Chapter 1

Cognitive Psychology and Educational Practice

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"Over the past quarter-century, no development in the social sciences has been more radical than the revolution—often referred to as the information processing revolution—in our way of understanding the processes of human thinking" (Simon, 1980a, p. 76). In this review I will examine the background for this remarkable statement, and will explore the educational implications of our new knowledge about the human mind.

As befits a "re-view," I begin with a quick scan of the historical paths that lead to present-day cognitive psychology. Next I present what I see as major facets of our current conceptions of human cognition, concentrating first on the architecture of the mind, and second on mental activity. I then turn to education—what do we mean by the educated mind, and how does the school foster intellectual growth? This section moves next to a consideration of some promising applications of cognitive theory and research for the improvement of educational practice.

This review is more an essay than a compendium. I have sought to represent major trends in cognitive psychology, while emphasizing works that seem most promising for educational practice. The conception of education presented in this chapter is not all encompassing, but is designed to match concepts and issues central in the thinking of cognitive psychologists. The paper is unabashedly theoretical, and some of the ideas are admittedly conjectural. My aim is to "accentuate the positive." The spotty character of our research knowledge, the apparent complexity of many behavioral and social phenomena, the practical barriers in the way of

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implementing research findings—such concerns receive little notice in this paper. The reader interested in a more critical account can satisfy this need elsewhere (Cronbach, 1975; Rohwer, 1980; and especially the thoughtful comments on cognitive psychology by Jenkins, 1981).

AN HISTORICAL PERSPECTIVE

Contemporary cognitive psychology is, as Simon suggests, the result of a fundamental redirection of psychological theory and research during the past few decades. In this section, I will review the major developments during three epochs of this history: behaviorism, the watershed of the 50s and 60s, and present-day cognitive psychology (also cf. Simon, 1980b).

Behaviorism. At mid-century, the behaviorism of Thorndike and Watson dominated American psychology. The approach focused on the empirical relations between stimulus and response. The theoretical efforts of Hull and Spence amounted to curve-fitting overlays; they were close kin of Skinner. There was great emphasis on learning, on the acquisition of simple skills over brief periods of time. Members of this school assumed the existence of basic learning principles of broad generality over organisms and situations. Rats, pigeons, undergraduates, children, mental retardates—the nature of the learner mattered little. Tasks were selected for convenience (e.g., t-maze, button press, nonsense syllable).

The behaviorist tradition was marked by a driving optimism (Thorndike, 1910) partly justified by the practical utility of some of the methods and findings. Hear Neisser's (1976) account:

> Watson and his successor Skinner maintained that people are infinitely malleable, and that the consequences of human behavior are crucially important. . . . These claims are . . . widely accepted, judging by the increasing use of behavior modification and behavior therapy in many contexts. (p. 4)

Behaviorism had its roots in "relevance," in American functionalism. The neobehaviorists set their sights to solving practical problems in education, mental health, and elsewhere (e.g., Dollard & Miller, 1950; Melton, 1959; Skinner, 1959).

Behaviorism attained its zenith in the early and middle 1950s. Hull's *A Behavior System* was published in 1952; Spence's *Behavior Theory and Conditioning* came out in 1956. Osgood (1952) and Skinner (1957) both proposed behavioristic treatments of language. But the times, they were a-changin'.

The new mental chemistry. In 1950, W. K. Estes published a brief paper, "Toward a Statistical Theory of Learning," putting forward a modest proposal about what might go on in the "black box" of the mind (Estes was a student of Skinner). To be sure, the proposal did not appear earth shaking;

Estes described experience at any moment as a collection of atomistic stimulus elements, each striving to have its say about the response choice. On the surface, stimulus sampling theory appeared only a refinement of associationism, but it was enough to open Pandora's box.

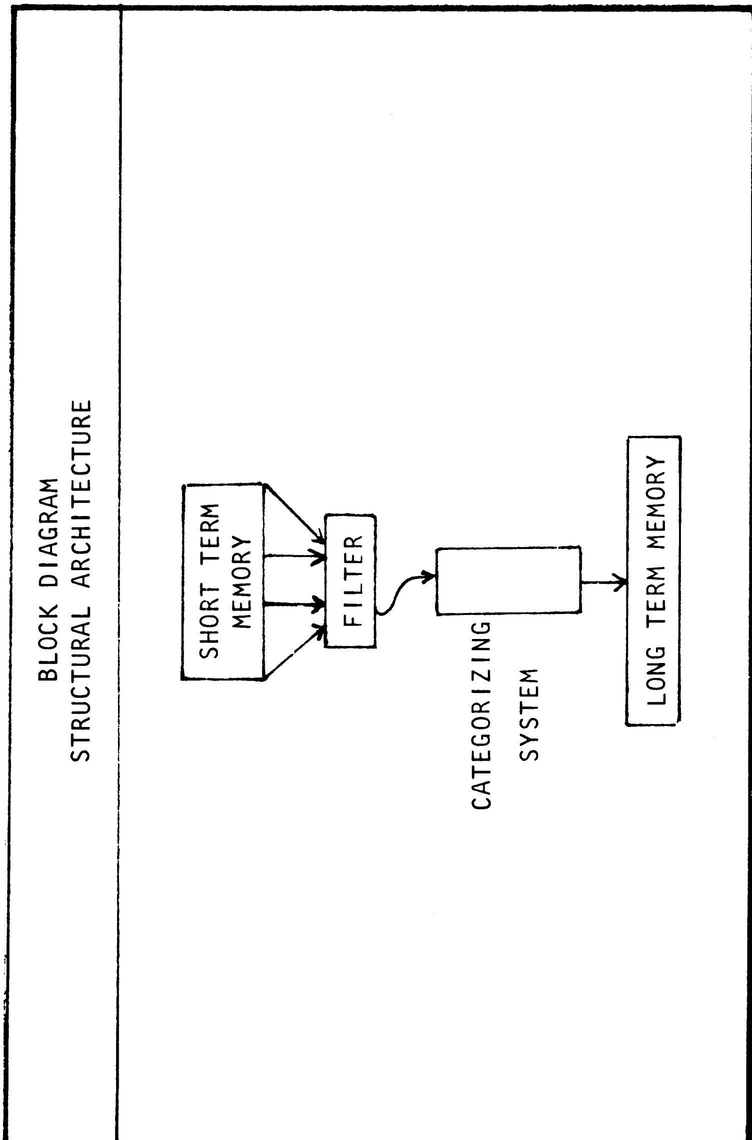
Some colleagues might argue that my mention of Estes' (1950) paper is premature. Be that as it may, it is clear that by 1956 something was afoot—significant papers were published by Miller, Newell and Simon, and Bruner, Goodnow, and Austin. The next year Chomsky's (1957) *Syntactic Structures* appeared, followed shortly by important works from Broadbent (1958) and Miller, Galanter, and Pribram (1960). *The Handbook of Mathematical Psychology* (Luce, Bush, & Galanter, 1963) contained a great deal more than mathematics. Neisser's *Cognitive Psychology* (1967) was a landmark. In the years that followed, it became increasingly clear that a new psychology was emerging (e.g., Anderson, 1980; Bransford, 1979; Haber, 1968, 1969; Lachman, Lachman & Butterfield, 1979; Lindsay & Norman, 1972; Newell & Simon, 1972).

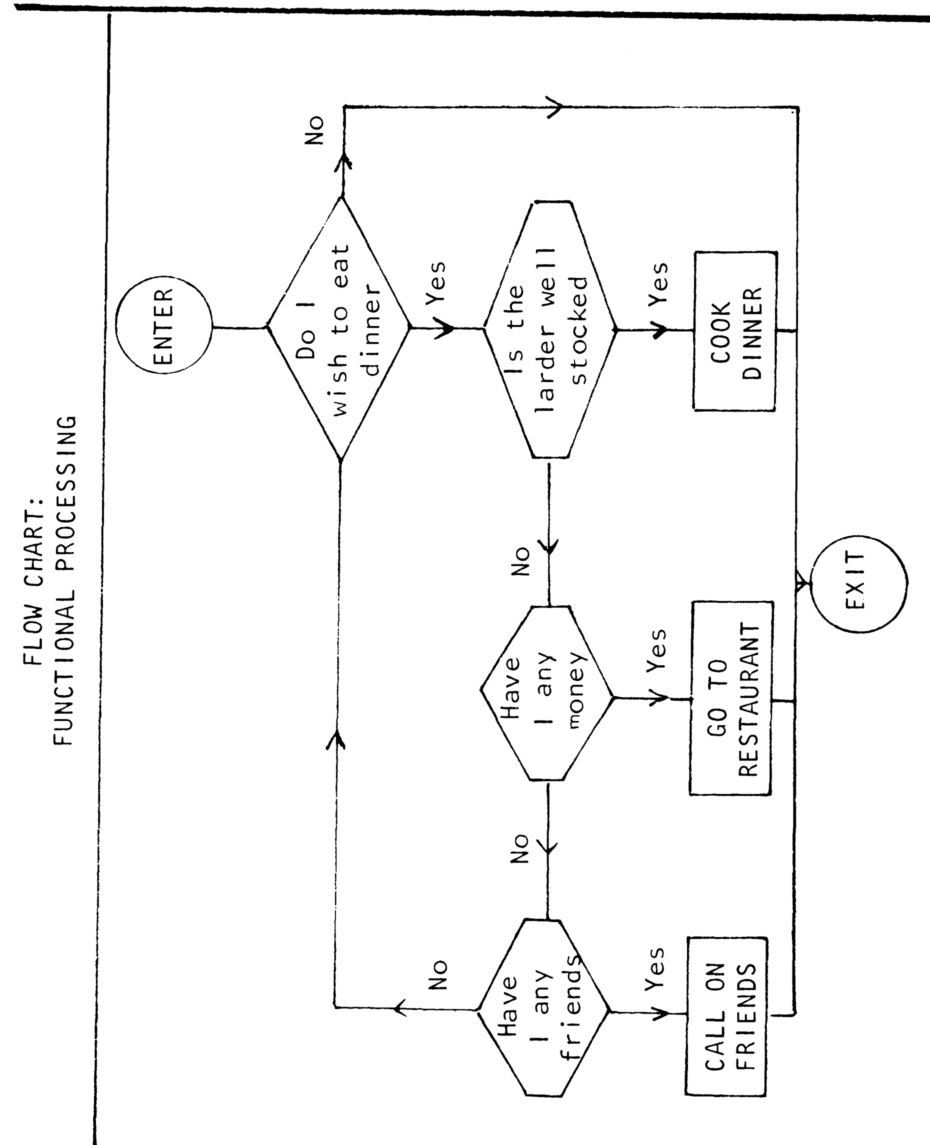
Two features distinguished the new paradigm. One was the infusion of new techniques for theory development. I have already mentioned Estes' stimulus sampling theory (Estes, 1959; Neimark & Estes, 1967), which evolved into a system of remarkable proportions. In addition, there were developments in signal detection theory (Green & Swets, 1966), rational decision making (Simon, 1980a, reviews the history), transformational grammar (Miller & Chomsky, 1963), and information theory (Garner, 1962.)

The second feature of the psychology was a renewed effort to understand the nature of mental activity. Psychologists had originally relied on introspection to understand the mind. The method informs us about the content of thought, but reveals precious little about the process of thinking. By judicious combinations of innovative theory and methodology, cognitive psychologists tried once more to trace the mind's pathways. Reaction time became a critical indicator—S. Sternberg's (1963) paper, a major advance, showed that it was possible to identify cognitive stages by decomposition of reaction times (also cf. Chase, 1978; Posner, 1978; R. J. Sternberg, 1977).

The main point is that it became legitimate to talk about what was going on in the mind. Mathematical psychologists began to discuss learning as changes in mental states and in the level of storage. With the gradual emergence of the computer as an analogy, it became increasingly natural to talk about *short-term* and *long-term memories, control processes* and *executive routines, storage capacity, decay rates, selective filters,* and the like. The study of attention became respectable again, and it was even possible to investigate consciousness (G. Mandler, 1975). In the 40s and 50s, the undergraduate subjects in the psychology laboratory worked mostly on learning nonsense syllables and solving puzzles involving simple geometric

FIGURE 1. Theories of cognitive processes (after Broadbent, 1975).




FLOW CHART:
FUNCTIONAL PROCESSING
ENTER
Do I wish to eat dinner
No
Yes
Is the larder well stocked
Yes
COOK DINNER
No
Have I any money
Yes
GO TO RESTAURANT
No
Have I any friends
Yes
CALL ON FRIENDS
No
EXIT

forms. By 1960 they began to encounter simple sentences, and by 1970 they might have been asked to study short paragraphs and even more extended prose. Clearly, psychology had entered a new era; cognitivists had undertaken the study of a new mental chemistry (Estes, 1960).

Cognitive (psychology and computer) science. During the past 10 years the computer metaphor has been adopted and transformed by psychologists and their colleagues in artificial intelligence. The merger, generally referred to as cognitive science, is a blend of the two disciplines, but has some unique features of its own (Norman, 1981).

In my reading I have encountered two approaches to the definition of cognition: one emphasizes function (how does the mind operate?), and the other focuses on structure (how is the mind built?). The first is represented by Neisser (1976): "Cognition is the activity of knowing: the acquisition, organization, and use of knowledge" (p. 1). In this definition, the emphasis is on the flow of information through the mind; it fits well with the conception of cognition as information processing. This perspective on human thinking is also remarkably compatible with the compelling account offered by William James (1890) a century ago.

Glass, Hollyoak, and Santa (1979), in contrast, emphasize the structural features of the mind and how these features are organized to support the processes of thought: "All our mental abilities—perceiving, remembering, reasoning, and many others—are organized into a complex system, the overall function of which is termed *cognition*" (p. 2). One can describe the structural elements of a computer—what the major components are and how they are connected—as distinct from the programmed routines that may be operating in the machine at some point in time. By hardware I do not mean the "nuts and bolts," but rather the structural plan or *architecture* (Campione & Brown, 1978; Snow & Lohman, 1981).

The contrast between structure and function is illustrated by Broadbent's (1975) distinction between block diagrams and flow charts (Figure 1). Diagrams like those in Figure 1 have served an important role in psychological thinking, and both forms of representation have proven rich sources of concepts. Unfortunately, these tools have often been employed in a relatively undisciplined and unparsimonious manner. It is not uncommon in psychological (and educational) writing to find these two modes of representation confusingly intermingled. Difficult conceptual issues have been concealed by drawing a box around them. Information-processing diagrams are presented more often as hunches rather than as formal theories. The informal treatment leads to a proliferation of parameters. In the limiting case, the computer metaphor takes the form of a computer program: mental activity is represented by as many lines of code as the theoretician cares to write. Scientists generally seek representations that are as parsimonious as possible—at the very least, a model should be no more complicated than the data it represents (Snow, 1973). Whatever the value of information-processing models—and I think we have learned a great deal from them—Occam's razor has clearly been dulled by the exercise on many occsasions.

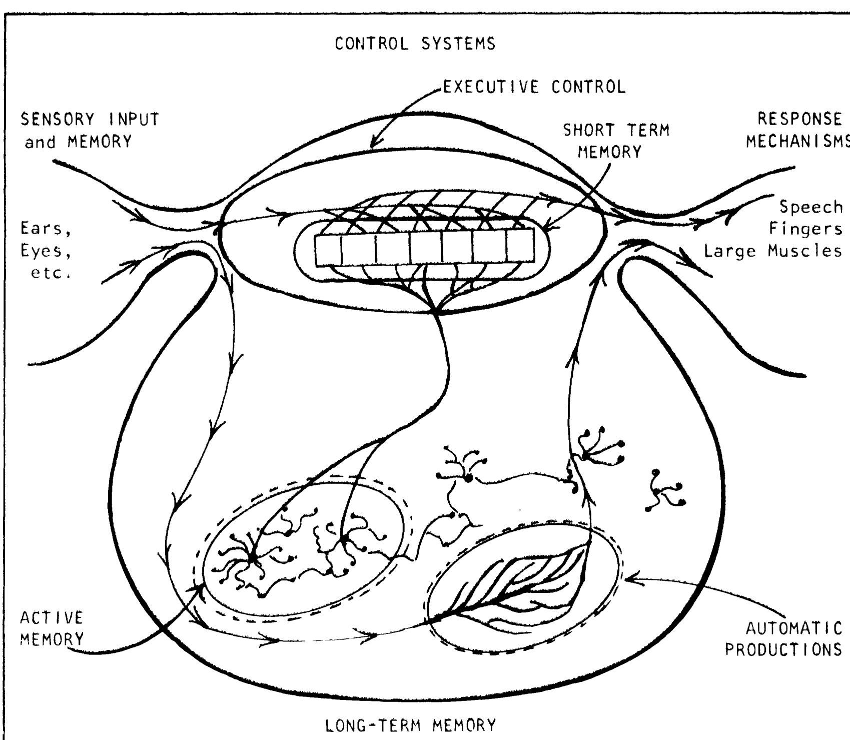
PRESENT-DAY CONCEPTIONS OF COGNITION

In this section I present an overview and selected findings from the past two decades of theory and research on cognitive psychology. I discuss first the architecture of the human mind (the structures that undergird cognition). Then I describe some representative work on processing (the manner in which human beings program their mental resources to perform particular tasks).

The Architecture of the Mind

In Figure 2 is a plan of the human information-processing system, which will guide the discussion in this section. In addition to long-term

FIGURE 2. Contemporary version of the structure of the human information-processing system.



memory—the chief repository of knowledge and experience—the model includes mechanisms for immediate storage of sensory inputs, for selection and control of information, and for short-term storage of small amounts of data:

> A few basic characteristics of the human information-processing system shape its problem-solving efforts. Apart from its sensory organs, the system operates almost entirely serially, one process at a time, rather than in parallel fashion. This seriality is reflected in the narrowness of its momentary focus of attention. The elementary processes of the information-processing system are executed in tens or hundreds of milliseconds. The inputs and outputs of these processes are held in a small short-term memory with a capacity of only a few (between, say, four and seven) familiar symbols, or *chunks*. The system has access to an essentially unlimited long-term memory, but the time required to store a new chunk in that memory is of the order of seconds or tens of seconds. (Simon, 1978, p. 273)

Sensory input and perception. Egeth (1977) provides a cogent summary of research on the sensory and perceptual components of human information processing:

> [M]any investigators . . . suggest there is no attentional bottleneck impeding perceptual processing. These . . . findings suggest a model of processing that has the following characteristics: (a) Perceptual processing may proceed on several independent channels simultaneously; (b) any input receives the same perceptual analysis regardless of whether or not it is "attended" and (c) stimulus encoding is effortless; capacity limitations in human information processing are due to stages subsequent to encoding. (p. 278)

People take in data from the outside world through a variety of sensory organs, each linked to a temporary storage system allowing brief retention of a substantial amount of information. During the retention interval, which may last no more than a few seconds, some pieces of information are selected for analyzing, recoding, and more permanent storage. These processes vary somewhat depending on the sensory system and the stimulus configuration. For instance, certain stimulus patterns are naturally perceived as blobs, whereas others are easily separated into elemental components (Lockhead, 1972). These natural predispositions can be enhanced by design and by experience.

It is clear that our sensory and perceptual systems can support a wide array of mental activities over and above those which they served early in man's history. A notable example is seen in the adaptation of vision to reading. Evolution did not fashion the eye and visual memory for the scanning and decoding operations required in skilled reading. Nevertheless, virtually everyone can learn to accommodate the visual system to the requirements of the reading task—some children may experience difficulty in learning to read, but these problems are seldom due to visual or perceptual inadequacies (Calfee & Drum, 1978; Vellutino et al., 1975).

Response mechanisms. This review focuses on *thought,* but it is important to take note of the cognitive basis for *skilled action*, by which I mean fluency in handwriting, physical education, the performing arts, and vocational education. In these and related areas, it is important to examine the relation between knowing and doing.

Research on skilled performance provides some valuable generalizations (Bilodeau, 1966; Fitts & Posner, 1967; Keele, 1973, Pew, 1974; Posner & Keele, 1973). First, though experience leads us to believe that we execute skilled actions continuously in time, research shows that we more typically perform according to a sequence of preplanned segments. The person selects a routine that should produce a desired outcome, and then the routine runs off more or less on its own. The individual checks to see what is happening every once in a while to ensure that things are still on the right track. Skilled actions do not generally require a lot of conscious thought.

How does the person acquire the routines that are the basis for skilled performance? The answer is *practice with feedback.* The number of times a student has performed a task is a good index to skill level, if guidance was adequate to keep the student on the right track. "[K]nowledge of results is the single most important variable governing the acquisition of skillful habits" (Irion, 1966, p. 34).

It is also important for the student to perform the task in the variety of situations that he or she is likely to encounter so that he or she has experience in adapting the performance to contextual variations. To be sure, an individual may "invent" a routine through practice: skaters, gymnasts, artists, and musicians often create new routines by trying them out, rather than preparing a plan in advance.

I will not dwell any further on the topic of the "response"; this section can be viewed as a placeholder to mark the importance of cognitive processes in skilled performance. Behavioral psychologists (and animal trainers) have shown that organisms can be taught skills without any attention to the underlying cognitive mechanisms. Such demonstrations have important practical value, and students should be trained in relevant skills; they also benefit from an understanding of how training operates so they know how to augment and adapt their collection of skills to meet life's changing demands.

Control systems: Planning. How does the individual select from the multitude of options in the stimulus information and response feedback available at any moment in time? One thing is clear, the human information-processing system can concentrate on only a small number of elements at any one point in time. The mind must choose continuously what to think about and how deeply to think about it.

This portion of the mind's work is generally ascribed to executive or control processes. Brown (1978) has described these processes in the following way:

> The . . . problem-solving skills . . . attributed to the executive [include] predicting, checking, monitoring, reality testing, and coordination and control of deliberate attempts to learn or solve problems. (p. 78, also cf. pp. 82ff)

An effective control system must be goal-directed, must have extensive contact with what is going on outside the organism, must be aware of the repertoire of responses available for action, and must stay in contact with the consequences of action once initiated. The theme of executive plans appears frequently in the analyses of cognitive psychologists (e.g., Miller, Galanter, & Pribram, 1960). Bower (1975) uses the following language:

> [T]he top-level routine is called the *executive*. [It] calls routines at the next lower level and keeps track of where these subroutines are to return their results. The executive monitors the number of subgoals being generated using a particular method (say, in a problem-solving situation). It also evaluates (from feedback) how the current plan is progressing. The executive may interrupt and switch to another subgoal either if that other one suddenly becomes more important or it the current method of attack on a subgoal seems not to be progressing satisfactorily, for example, if it exceeds a work limit. The executive also notices when a subgoal has been completed so that its results may be used in selecting the next step or next goal to be worked on. (p. 32)

As you can see from this excerpt, cognitive psychology admits the importance of plans and goals in human thought. The individual is partly driven by the body's need to maintain homeostasis. The immediate demands of the environment also call forth responses—if something novel happens, the person must direct attention to the situation. In addition to these "natural" demands, human beings act on the basis of knowledge and intention. Much of what we do comes about by reflective consideration of alternative courses of action, rooted in analysis of previous experiences, supported by language and the capacity for symbol use, guided by the counsel of others (including parents, teachers, employers, and so on), and subject to continuous revision as circumstances dictate.

The earlier behaviorism tended to look at rather narrow slices of life. Present-day cognitive psychology includes in its vocabulary the concepts needed to deal with broader aspects of the individual's existence. It is a relatively small step from talking about the grammar of a story to discussing the "syntax" of a student's experience in school.

Control systems: Attention. While the structure of executive systems remains somewhat sketchy at present, attention is one area in which neurophysiological findings support psychological analyses (Pribram, 1973; Pribram & McGinness, in press; also cf. Teyler, 1978). For instance, we know that those aspects of attention having to do with "noticing" and with registering information are carried out by specific midbrain/forebrain structures. The initial *phasic* response to novelty comes about through

> [A] system of neurons responding to the amount of input to them by maintaining or incrementing their activity. This core system extends from the spinal cord through the brain stem reticular formation [a diffuse network that extends through all parts of the brain, linking the senses, association areas, and motor cortex], including the hypothalamic sites [the body's "thermostatic" control, and the area for initiation of emotional responses]. (Pribram & McGinness, in press)

When something new happens, this network is capable of immediate and widespread response. Longer duration *tonic* responses depend on a different set of neural structures, within which it is possible to distinguish between registration of information in memory (linked to what is known as the hippocampus) and registration of information in "awareness" (linked to the amygdala).

The importance of the neurophysiological findings for cognitive science lies not so much in the identification of particular brain sites as in the isolation of specific mental operations. The work mentioned above supports distinctions in attention that also appear in behavioral research (cf. Piontkowski & Calfee, 1979):

Alertness—the general level of awareness and sensitivity to the environment;

Selectivity—the scanning of the environment in search of salient and goal-appropriate features;

Concentration—the focal act of attention, where selected elements are analyzed in detail.

We now have good reason to consider separately the organism's general alertness and response to novelty, in contrast to the other phenomena that have in the past all been lumped under the general heading of attention. It seems to make sense to distinguish further between the perceptual processes that underlie the selection of relevant cues, and the short-term memory processes that provide temporary storage space for concentrating on a few chunks of information. We lack firm evidence on how the brain handles these tasks, but the behavioral research for this distinction is quite substantial, as we shall see.

Control processes: Short-term memory. Bower (1975) provides a succinct but comprehensive description of that part of the control system commonly referred to as short-term memory:

> Short-term memory (STM) is the active part of the central processor that holds the symbols currently in the focus of attention and conscious processing. (p. 43)

Short-term memory is the chief "port of entry" for information that is novel, salient, or otherwise identified to be of critical importance. The reference to consciousness is notable and will be discussed later.

The extensive research on short-term memory leads to the following conclusions. This system has limited capacity. Miller's (1956) magic number was 7 ± 2. G. Mandler (1967) thought that the limit might be five elements, and Simon (1981) estimated the capacity to be only two elements. These discrepancies may reflect different methods for defining and measuring a "chunk" of information. What is clear is the sharp limit on the number of things a person can think about at any one time.

The chunks for verbal material are typically encoded in acoustic-verbal form; other codes are employed for other modalities (e.g., pictures, smells, textures). Information may be retained for 30 seconds or more if the memory is not overloaded and if rehearsal is not prevented. If the person works at rehearsing, a small number of ideas and relations among them can be remembered for quite awhile. The system is good at preserving the order of incoming information, which makes it handy for thinking about sequences of ideas like sentences or "real-life" episodes.

The limited capacity of short-term memory is less restrictive than might first appear because of the capacity to encode an incredible amount of information into a single chunk. We often think of short-term memory as the temporary repository of materials like number strings: to remember 994-3768, each number is placed into one of the slots in short-term memory. In fact, we can use those same slots to store tokens that point to complex collections of knowledge, such as what I know about the *normal distribution equation,* the *general linear hypothesis,* or the *analysis of variance.* With practice, a person can learn recoding techniques which make more effective use of short-term memory. It helps to divide a long string into substrings (most of us do this with telephone numbers), especially if these have some internal organization (e.g., Hagen, Jongeward, & Kail, 1975; for a remarkable demonstration of the effect of training on short-term memory, see Chase & Ericsson, 1981).

Short-term memory is ideally suited to the processing of ordered word strings like sentences, and it is easy to see that the evolution of this system was critical to the development of language. The component operates like a tape recorder loop, storing a small number of messages while these are interpreted. Once a sentence has been transformed into a single coherent idea, the information is transferred into long-term memory—by then the next sentence is coming in, erasing the previous record.

Short-term memory operates as a "scratchpad" for thinking, for organizing, for imagining, and for planning. When we speak of conscious awareness, we probably mean the contents of short-term memory. Despite its important role as a part of the control system in human thought, short-term memory would be a troublesome bottleneck if all messages had to pass through this system. Fortunately, we bypass it most of the time.

Control systems: Automatic action. When the individual is acquiring new knowledge and skill, when an approach that worked previously does not knowledge and skill, when an approach that worked previously does not produce the expected outcome, when emergency conditions put too great a demand on the system—circumstances like these cause short-term memory to be engaged. We sense a concentration of mental energy and effort.

In other instances, a task is performed by readily available, virtually automatic routines, which place little or no demand on attention (LaBerge & Samuels, 1974). Some of these routines are built in: the reflexive jerk when some part of the body is pained is automatic, and it is only after action is taken that we "think about it." Other routines become available only through extensive practice. My present focus is on the latter type of automatic action, and the fact that not only can complex tasks be mastered, but they can reach a level of automaticity where they effectively circumvent the limited capacity bottleneck.

The distinction between automatic and effortful mental processes has a long history. Recent theoretical and empirical work has helped to clarify the distinction (also cf. Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977):

> [O]perations that drain minimal energy from our limited-capacity attentional mechanism are called *automatic*; their occurrence does not interfere with other ongoing circumstances. They occur without intention and do not benefit from [further] practice. Certain automatic processes . . . are ones for which humans are genetically "prepared." These processes encode the fundamental aspects of the flow of information, namely, spatial, temporal, and frequency-of-occurrence information. . . . Other automatic processes develop through practice and function to prevent the subcomponents of complex skills from overloading our limited-capacity system.
>
> Contrasted with these processes are *effortful* operations such as rehearsal and elaborative mnemonic activities. They require considerable capacity and so interfere with other cognitive activities also requiring capacity. They are initiated intentionally and show benefits from practice. (Hasher & Zacks, 1979, p. 356)

The phenomenon is easily experienced. For most of us, reading has become such an automatic response that translation from print to language overrides all other responses. The Stroop test (Schiller, 1966) provides a ready demonstration of the phenomenon: write the word "RED" on a card with a bright blue marker, ask a friend to be ready to name the ink color, and then flash the card. The delayed response is generally dramatic evidence for the dominance of the reading response. The effects of shunting an automatic response through the executive is also easy to demonstrate: Read the next paragraph while attending to your eye movements, and to the letter-sound and configurational characteristics of the words. You will read more slowly, understand less, and experience considerable frustration.

The operation of automatic productions is shown in Figure 2 as a flow of information directly to the appropriate locations in long-term memory, and thence by well-established associations to a preplanned set of responses—

once the executive has determined that a situation can be handled, then no further action is needed, and the capacity can be used for other purposes. As long as the direct link between stimulus and response produces the desired outcomes, a task will place little or no demand on the limited capacity short-term memory. (I am using stimulus and response metaphorically; the situation and the task may be quite complex.) Whenever the operation begins to falter, or when unexpected or emergency conditions are encountered, the executive shunts information through short-term memory so that the situation can be examined more carefully. Under these conditions, the person has a problem to solve.

The competent person has internalized many routines of a highly automated character, which allow him or her to carry out complex tasks in routinized fashion while simultaneously attending to other matters that require focal attention and thought. In this way we are able to carry out multiple tasks simultaneously, as long as we do not overload the system. It helps if the tasks are relatively distinctive. Discussing plans for an upcoming meeting while driving your car on the freeway is possible because driving is largely automated, but it helps that driving is not closely tied to the planning activity. Automation of one set of skills may be essential to learning and performing a second task. The student is hard pressed to solve long division problems if considerable attention must be devoted to the subsidiary skills of adding, subtracting, and multiplying; for a reader to comprehend new and unfamiliar ideas in text is difficult when he or she must spend time and mental energy on the mechanics of decoding or grammar.

Automation entails speed and fluency, as well as accuracy and understanding. As such, it goes beyond the concept of mastery learning as the latter is promoted today (Block, 1974). "Being correct 80 percent of the time" gives little assurance that performance has become automatic. Nor is it enough to understand the principles for performing a task; such understanding is important in its own right, but in an automated skill understanding fades into the background, available for reference when necessary. Performance becomes automated through practice under varied conditions. Aside from motor skills, "overlearning" is not much mentioned in modern-day psychology, but the older literature shows clearly the benefits of practice for mastering a skill to the point of fluency (Fitts & Posner, 1967, Ch. 2).

Long-term memory: Storage. As the label implies, long-term memory is the repository of everything that a person knows: experiences, facts, beliefs, skills, feelings, and so on. While much remains to be discovered about this system, a great deal has been learned about it in the past several years. I will review some of the major findings in this section and the next.

The capacity of long-term memory is, for all intents and purposes, unlimited. As Dooling and Christiaansen (1977) express it:

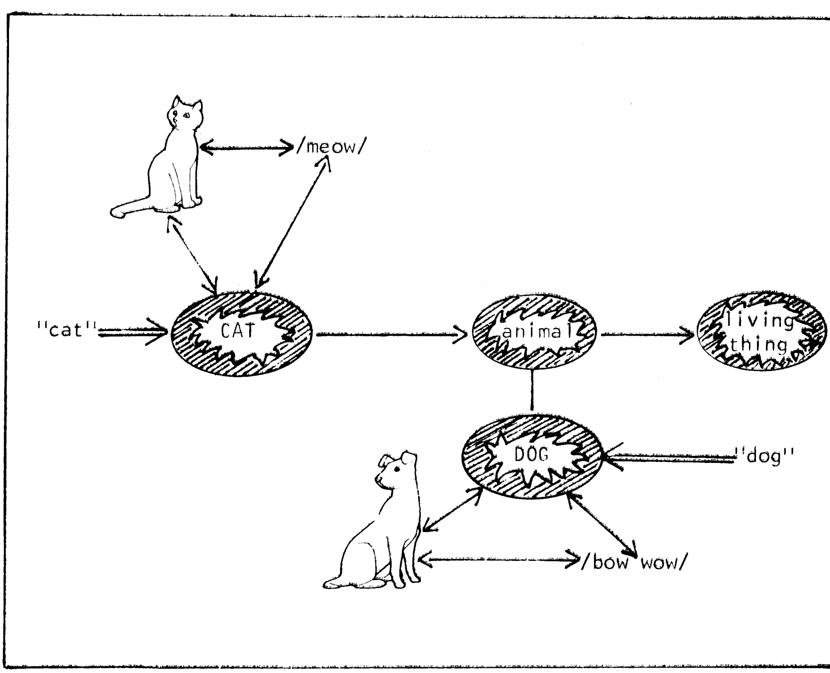
> What we remember is enormous. And even more remarkably, most of what we remember has been learned effortlessly and naturally. Our memories seem built for giving high priority to memory codes which have wide generality and importance. We seem to put stress on memory information that will allow us to be approximately correct most of the time, though rarely exactly perfect. (p. 36)

I suspect that these authors overestimate the "effortlessness" and "naturalness" with which we learn what we know about the modern world; nonetheless, the capacity, versatility, and adaptability of long-term memory are incredible.

Information in long-term memory is arranged in *nodes*, which are interwoven into *associative networks*. Figure 3 is an example of what a prototypical network might look like. Arrayed around each node are kinds of information that might be associated with it.

The exact nature of a node remains open to question. As a matter of fact, not all cognitive psychologists are happy with this term—they prefer terms

FIGURE 3. Example of a prototypical network in long-term memory—by each node is information associated with it (after Glass, Holyoak, & Santa, 1979).



like *idea, concept,* or *word.* I choose the more abstract label (node—a knot or complication) to indicate my own uncertainty about how best to define this entity.

The most basic question about the node is whether it exists as a separate entity (Ross & Bower, 1981). One possibility is that the node has a reality of its own—Posner and Keele (1968) theorized that prototypes exist as summaries of related experiences. According to this point of view, the mind is continuously engaged in analyzing experiences, searching out parallels and analogies, and constructing mental programs that incorporate the dominant features that typically characterize a related set of experiences. These summary representations correspond to the shaded circles in Figure 3.

A second possibility puts more emphasis on associative linkages—similar experiences are stored near one another in memory, and when any one is remembered there is a general activation of all the others. As an analogy, imagine going into a darkened, "energy-efficient" library in which only a small section can be illuminated at any time. As a searcher moves from one area to another, localized "concepts" are defined by the collection of items that is in view at that time. Thus, the concept of "cat" in Figure 3 has no existence apart from the collection of perceptions, experiences, labels, and so on. When you see a cat or hear the word cat, the nearby regions in long-term memory are illuminated and all these recollections available for reflection comprise a node.

Both views fit well with the multicomponent conception first proposed by Bower (1967), but also discussed by several other researchers (Anderson & Bower, 1973; Craik & Lockhart, 1972; Norman & Rumelhart, 1975; Posner & Rogers, 1978; Schank & Abelson, 1977). While these approaches differ in certain details, they all share the notion that any idea in long-term memory has many facets to it, any of which can serve as an entry point to the idea. Once activated, the idea can then be rotated like a diamond, so that first one facet and then another is highlighted.

Long-term memory: Events and concepts. Whatever their exact makeup, the elements that comprise memory vary significantly in their origin, content, and richness. Much of what we remember originates from common, everyday experience; these are the "natural" memories alluded to by Dooling and Christiaansen (1977). Their content is typically perceptual and episodic; facts about the "where and when" of events are important features of such memories, which tend to be quite rich and concrete.

Other ideas are more impersonal and analytic in character. These memories more frequently come from schooling or formal training. The content is verbal and conceptual, and while a great amount of information may be available, it often contains little in the way of commonplace perceptions.

The contrast drawn above has been noted by several investigators. To understand the difference, consider the memories that give rise to a statement like "Chicago is in Illinois" (semantic) versus "I saw Fido bite Bill yesterday" (episodic). Tulving (1972) refers to the *episodic-semantic* distinction, and G. Mandler (1979) has talked about *schematic* and *categorical* organizations in memory. Pribram (1980) discusses the differences between the neurological structures that are responsible for *predication* (pragmatic, episodic, syntactic, verb-based memories) and for *nomination* (semantic, abstract, noun-based memories). Glass et al. (1979) refer to the Yin and Yang of memory: the analogic and the analytic.

Some researchers now debate the importance in long-term memory of one or the other form of storage, or whether any such distinction is needed (Anderson & Ross, 1980). It seems likely that many nodes in long-term memory are combinations of concrete and abstract information. Whatever the merits of the existing research, the contrast strikes me as practically useful, especially in comparing formal and informal learning (Calfee & Freedman, in preparation). One of the chief functions of education is to provide the individual with a wide array of conceptual and semantic frameworks for arranging knowledge in organizational networks that differ substantially from the results of natural experience.

While the digital computer has provided a fruitful analogy for cognitive psychologists, the uniquely associative structure of the mind may be the clue to the differences between long-term memory in human beings and in computers (Estes, 1980). For instance, human memory is content-addressable: knowing what you are looking for will lead you directly to the information. Computers are generally location-addressable: the program has to know the particular place in memory where a piece of information is to be found, and then it can analyze what it has found.

Estes points up another important distinction between human and computer memories. In the computer, information is stored in a precise "all-or-none" fashion. The number 3.1416 is either present at a particular location or it is not. Human memories tend to be richer, more fine grained, less precise, but more informative. The mind can mimic a computer; with training, a person can duplicate some features of the computer, or the library, or almost any device we have yet created for handling information. At its core, however, the mind is a general purpose system for helping the person in his or her dealings with the world:

> The human memory seems to be not at all like a storeroom, a library, or a computer core memory, a place where items of information are stored and kept until wanted, but rather presents a picture of a complex, dynamic system that at any given time can be made to deliver information concerning discrete events or items it has had experience with in the past. In fact, human memory does not, in a literal sense, store anything; it simply changes as a function of experience. (Estes, 1980, p. 68)

The richness and strength of an idea in long-term memory depends largely on two principles that have been around at least since Aristotle: frequency and contiguity. The more often we encounter a particular kind of experience, the richer its representation in memory; the more closely two experiences occur in time and space, the greater the likelihood that the arousal of one idea will evoke the other. Frequency and recency have been the behaviorists' calling cards—Watson used frequency as the basis for his learning theory and Guthrie relied on contiguity as the foundation for his system (Hilgard & Bower, 1975). There is a certain irony in the notion that these concepts, while insufficient to explain changes in observable behavior, are essential in understanding why we remember things the way we do.

Notice that these principles say nothing about the organization of ideas. Human beings seem to have an inborn tendency to search for structure, and long-term memory operates most efficiently when and if the arrangement of a body of information matches some preexisting mental structure. Knowledge is parsimonious when properly organized; but the organization must highlight frequent events and respect the relatedness of events in time and space. We need to remember what things happen together most of the time.

Long-term memory: Retrieval. The preceding section focused on how information is stored in long-term memory, and the variables that determine the likelihood of a set of ideas being linked in an associative network. This section will examine what happens when information is retrieved from long-term memory.

Psychologists often vary the testing procedure as a way of distinguishing between storage and retrieval processes. A *recognition test* is assumed to probe fairly directly at the spot in memory where an idea is stored, whereas a *production test* requires individuals to search for the ideas on their own initiative. In a recognition test, the person is given a "copy" of a previously encountered event, and is asked to say whether he or she recognizes it or can pick out the original event from a set of similar alternatives—the multiple-choice test is a commonplace example of a recognition test. In a production test, the person is given a cue or a set of instructions and must generate the answer (e.g., essays, spelling tests, etc.).

Numerous investigations comparing recognition and production have shown that different mental operations go on during the storage and retrieval of information. The differences are clearest when the recognition test uses distinctive alternatives—you can construct a multiple-choice test with answers that are so alike that the test is more difficult than writing an essay. Under such conditions one finds little difference between recognition and production. Simon (1981, p. 80) estimates that storing an idea for simple recognition requires only a second, whereas storage for production takes 10 times as long. Why does storage for production take so long? One guess is that the key to success on a production task is not a "stronger" memory, but a better organized one.

Some time ago, Kintsch (1970) showed that organization had much more influence on production than on recognition. Subsequent research has shown that organization can also affect recognition, especially when there is a great deal to be remembered, when the alternatives are similar, and when there is a long delay between study and test (G. Mandler, 1981). Nonetheless, it appears that long-term memory does allow recovery of information that has been only barely noticed—the student about to take a multiple-choice test does well to expose her- or himself to as much information as possible. To be sure, thoughtful study and deep reflection may pay off if an item includes a plausible alternative besides the correct answer.

Writing an essay, showing how to solve a mathematics problem, explaining Newton's law of gravity, summarizing a passage which you have just read—these tasks generally require much more than locating in memory the parts of the answer. Since a "copy" is not provided to help the person locate what he or she knows, self-initiation is essential. The student must have a systematic plan for retrieving the information, and for reproducing it in a coherent fashion. Under these circumstances, the advantage goes to a well-organized idea and a well-rehearsed scheme for constructing the answer.

Long-term memory: Organization. I have been relying on your intuition to understand what is meant by "organization" in memory. In this section I will review some concepts and findings on this topic.

Organization matters—the principle goes back to Aristotle. It is commonplace that you should use what you already know as a basis for remembering something new. A great deal of what you "already know" is reasonably well organized; if you are educated in Western culture, you probably share many organizing principles with other similarly educated people. You know the number system, and operations on that system. You know the concepts of force, mass, inertia, and gravity, and probably have some sense of how they are related. You know several taxonomies, including those for animals, vegetables, and minerals. You know how a chicken is built, how a restaurant operates, the parts of a car, the plan of the solar system, and so on.

Some of this knowledge is attained as a result of living in a complex and organized environment. You have probably never been formally educated in the operation of a restaurant or on the floor plan of a modern home, but through repeated experience you have formed a well-organized concept of these and other social devices. Many structures in the minds of educated people result from schooling. These structures tend to be more abstract and analytic. Sometimes schooling and everyday experience combine: you can know how to carve a chicken without an explicit mental structure of how the chicken is put together; you can know from schooling how a chicken is built but lack the practical knowledge to cut up the bird; or you can have both types of knowledge.

Psychologists have discovered a great deal in recent years about how people use their existing store of organized knowledge as a base for remembering new things. In the 50s and 60s research focused on the recall of lists of words from semantic categories (foods, animals, kitchen utensils), and the conditions that facilitated the use of categorical information (e.g., Cohen, 1966; Tulving & Pearlstone, 1966).

In the late 1960s and into the 1970s, Bower and his colleagues undertook a series of investigations on mnemonics; mental images, "crazy" sentences, grouping strategies, and a variety of other devices were taught to college students, allowing them to increase the "memory capacity" over the usual laboratory results by orders of magnitudes (Bower, 1972). More recently, Bower and others have explored more complex memory structures, including those that underlie stories (Bower, Black, & Turner, 1979; J.M. Mandler, 1978; Rumelhart, 1975; Stein & Glenn, 1979), pictures (Friedman, 1979; Mandler & Ritchey, 1977), and expository prose (Meyer, 1975). These studies have shown that people rely heavily on structural commonalities for interpreting, storing, and recreating experiences. For instance, if a child is told a story that does not fit his internal model of a story, he will have trouble remembering it, and will tend to retell whatever he can remember by switching to the framework with which he is familiar.

The studies of the past 20 years have demonstrated the potency of organization in memory; they also suggest that people are flexible—any of several organizing strategies or schemas may serve equally well in a particular instance (e.g., Broadbent, Cooper, & Broadbent, 1978), although it is hazardous to switch frameworks in midstream (Tulving, 1962).

Psychologists have introduced several terms during the past several years as labels for the frameworks used to organize information in memory: schema (J. R. Anderson, 1976), frame (Goldstein & Papert, 1977; Minsky, 1975), prototype (Posner, 1969), grammar (Mandler & Johnson, 1977; Miller & Chomsky, 1963), network (Anderson & Bower, 1973), along with hierarchy, matrix, and probably several others. While one can distinguish subtle shifts in meaning among various labels (e.g., de Beaugrande, 1981), my present purpose is served better by emphasizing the commonalities.

I will use *frame* to refer to the models in long-term memory for organizing information. While "schema" is perhaps the more common jargon today, and may have historical precedent (Bartlett, 1932), styles change, and Minsky's (1975) thinking about the organizing structures in memory seems a good starting point:

We can think of a frame as a network of nodes and relations. The "top levels" of a frame are fixed, and represent things that are always true about the supposed situation. The lower levels have many *terminals*—"slots" that must be filled by specific instances of data. Each terminal can specify conditions its arguments must meet. (p. 212)

The language is somewhat jargonny, but this tendency is a fact of life. Minsky is saying that a frame is a model consisting of a set of key elements and the relations among them, which summarize in a partly abstract manner what we remember in general about something. For instance, suppose someone asked you, "Tell me what a first-grade classroom is like in the United States." Your answer, which would have much in common with that of other people, would include a teacher, 20 to 35 students, an enclosed space, assorted pieces of furniture and other equipment, along with books and various items for teaching. These elements would not be randomly arranged—you would place the teacher in a superior relation to the students, for instance.

The preceding description comprises the "fixed" elements of the classroom frame; one might also add optional elements to the list, such as provision for an aide, or for an "open space" setting. You can also imagine a set of variations on a frame, alternative arrangements built around the same model. In fact, your concept of the first-grade classroom is probably a variant on a more basic framework called "the classroom." When asked to describe a first-grade classroom, you remember the basic "classroom" frame, and then add a set of modifications that convert it into the first-grade version.

When you encounter a specific instance of a first-grade classroom, when you try to remember a previous experience with such a classroom, when you mentally compare two classrooms—in all these instances you call forth the basic frame from memory, fill in the "slots" with specific pieces of information, and then you have a well-organized idea of a particular first-grade classroom, which can be handled as a single coherent chunk for any further thinking you may need to do.

A frame, then, is a specialized kind of memory useful in the storage and retrieval of other kinds of memories. The different labels for this concept reflect the variety of ways in which frames are created and used. I shall say more on this point in the next section. For now, let me simply note that some frames are the product of man's sensitivity to the recurring features in repeated experiences. We extract prototypes, we observe similarities, and we draw analogies all the time, with no training and without much conscious awareness. The 5-year-old's sentence grammar is an example. In contrast, other frames come about as a result of formal training and are applied in an analytic and conscious manner. The 15-year-old's use of sentence diagrams illustrates this point (for better or worse).

I will argue later that an important outcome of education is the acquisition of an enormous array of frames which can be used by individuals to organize information so that they can think about the complexities of modern society. Another important outcome of education is the individual's ability to create and employ organized knowledge in a conscious manner to simplify problem solving and enhance the chances of success.

Finally, let me mention that individuals differ markedly in this aspect of memory, and that one of the major facets of memory development between the ages of 5 and 15 is the acquisition of formal methods for dealing with information in memory. Most of the characteristics of the memory system discussed earlier are relatively invariant over individuals—the architecture of memory, the capacity of short-term memory, the basic mechanisms for storing and retrieving information appear quite similar from one person to another. When it comes to the availability of organizing devices and the disposition to use such devices, however, younger children are quite different from older children, some of whom possess a varied repertoire of memory devices and are quick to make use of them, while others seem to continue to rely on the same methods that they used when they were very young (Brown, in press; Hagen, Jongeward, & Kail, 1975; White, 1970). These differences can be traced to many sources: developmental, social, cultural, environmental, and perhaps even genetic endowment. For the moment, let me reiterate the likely importance of schooling as a factor in the initiation and maintenance of these differences.

Working memory. Several researchers have proposed the concept of a memory system somewhat more extensive than short-term memory, but distinctive from the permanent store of knowledge (Baddeley & Hitch, 1974; Bower, 1975; Feigenbaum, 1963; Greeno, 1974; Reitman, 1970; Simon, 1975, p. 272). The system is presented at times as a separate structure with its own functional characteristics, but more often it appears as a working space that serves as the locus of active, reflective thought.

Bower (1975) states that "one of the primary functions of working memory is to build up and maintain an internal model of the immediate environment and what has been happening in our world over the past minute or two. We may think of the working memory as containing a description of the *setting*, framework, or context within which the more dynamic alterations of the world before us are taking place" (p. 54). Bower goes on to suggest that we use working memory to update our knowledge of "what is happening" at the moment—ongoing events and information from long-term memory about similar events in the past join together to create the experience of the present—"This local model serves as a framework within which dynamic (small) changes are recorded . . . only the new, altered information must be focused on (in an active short-term memory) and entered as a new symbol structure or proposition into working memory" (p. 54).

This process is seen by Bower as important to perception, to the comprehension of sentences and sentence strings, and to planning and imagination, among others. In all these instances, data are selected from the present stimulus field, and integrated with knowledge of previous experiences to yield a perception, an understanding, an expectation, a plan of action, or some combination of these reactions.

While the operation of working memory is critical in the growth of knowledge, it is not necessary to invoke a new structure in the architecture of memory. We need not assume that information is "stored" in intermediate memory; instead, information is worked on in an activated area of long-term memory (Figure 2). This assumption leads one to inquire not about the unique structural and operational features of working memory, but rather about the operations in long-term memory for storing new information, for modifying previously stored experiences, and for identifying and retrieving the knowledge needed to deal with a present problem. Working memory is not time limited in any absolute sense. The retention of a topic depends on how long the individual continues to focus on it, which depends on the topic; it may be several seconds or as long as an hour. As Baddeley and Hitch (1974) note, working memory reflects the operation on long-term memory of short-term memory; capacity depends on the existing organization of previously stored information, and the time limits (how long can you remember what you have been working on) depend on the interest or "attention-capturing value" of the material being studied.

The notion of "spreading activation" has been in the memory literature for some time, but it remains an important concept (J. R. Anderson, 1976; Collins & Loftus, 1975). Experiences that are close in time and space are likely to be closely associated in long-term memory. The experience of the present moment calls forth previous experiences and associated events (Jenkins, 1974).

As mentioned earlier, nodes in long-term memory are multicomponential: any particular mode contains different pieces of information that convey distinctive experiential and conceptual relations (Bower, 1975). Human memory is *content-addressable*: the system searches directly for the information under investigation. (The computer generally operates as a location-addressable device: it has to be told where to find the information it is searching for.) Thus, I can highlight different perceptual characteristics of animals in your mind (what does a lion, zebra, cobra, condor look like?), or I might have you think taxonomically (rate the animals according to closeness of relation), or I can lead you to a functional characterization (how would you deal with each of the animals if you are forced to keep it as a household pet?).

Pribram, Nuwer, and Baron (1974) have suggested the hologram as a metaphor for memory storage and retrieval. The idea is that when experiences are stored, information is saved about the context and setting of the experiences. When we remember an experience at a later date, the context and setting reinstated at that time influence what we remember. If the context and setting are varied during an experience, the individual can remember the original experience from several perspectives, thereby capturing a fuller and more complete version of the original.

The storage of information in long-term memory during a "working memory experience" produces multiple-component entries that can be activated by any of its multiple features. The system possesses great potential for recognizing patterns, for establishing complex associative networks, and for analyzing problems of considerable intricacy. The system can also be overloaded, which can be avoided in several ways. First, we seldom have to remember something defined by one or two unlimited characteristics; more often, we are searching for a pattern that limits the range of activation. In the psychologist's laboratory a person may be asked to think about "all animals" or "all foods." It is easier to think about "farm animals" or "types of pancakes." To be sure, a person can range over broad domains, but such abstract levels of thought generally require a systematic framework, like that provided in formal education, for instance. Otherwise, experiences easily become encapsulated in long-term memory. These may be "recognizable," but have no effect outside of the immediate context. Both Brown (1978) and Greeno (1978a) recount that laboratory experiments designed by experimental psychologists may have just such a status. Brown, for instance, found little evidence that her young subjects transferred what they had learned in "metamemory" experiments beyond the laboratory experience. The children could not generalize beyond the experiment. They remembered that they had been in the experiments, but saw little connection between the laboratory training and other situations where it was important to think about how best to remember something.

If working memory operates through activation of a region in long-term memory, we have a ready explanation for many cognitive phenomena. As Bower (1975) argues, instantiation of a previous experience makes it unnecessary to "think about" everything in a present experience. If there is a reasonable match between present events and previous experience, then considerable cognitive economy will be achieved by "going beyond the information given," to use Bruner's (1957) phrase. Once in a while we make a mistake, but the cost of completely examining every situation is too great for the gain in accuracy.

The activation of a region in long-term memory can lead to changes in the information in that region, changes that may be incidental as well as intentional. For instance, Loftus and Loftus (1976; also cf. Jenkins, 1974;

Johnson & Raye, 1981) describe situations in which the memory for an event is altered by slight and casual experiences after the original event. The witness of a vehicle accident, when asked whether the driver noticed a yield sign, is likely to remember afterwards that the driver saw the yield sign when, in fact, it was a stop sign.

In the above example, the experience is only superficially attended, and the information in memory is sparse and superficial. More often, a change in long-term memory during a working-memory operation results from intentional elaboration, modification, and extension of the previous information. Simple tallying is a common occurrence: "I've experienced X once more." Other times a replica is stored with annotations that relate it to the original model: "I've experienced Y which was like X except for . . . ." Sometimes there is a modification of the original: "I thought I remembered X, but it should have been X′." Norman and Rumelhart (1975) have classified these operations in working memory under three headings: *Accretion* is the storing away of new pieces of information that are attention getting; *restructuring* is the arrangement of old and new information so that it makes more sense; *fine tuning* is the "correction" of memory to reflect more recent experiences and perceptions.

Up to this point I have discussed the operation of working memory on our memory for "raw experience"—on *nodes*, if you will. Of special relevance to education is the creation and use of *frames* as a result of working memory. I will focus on three questions: (1) How are frames created? (2) How are they used in storage of information? (3) How are they used for retrieval of information?

How are frames created? One clue about the formation of frames comes from research on prototypes (cf. Anderson, Kline, & Beasley, 1979, and references therein). If a person experiences a series of events that are similar in some fashion, the mind tends to extract the underlying generalities. The set of generalities, which may comprise a node in its own right, is referred to as a prototype. The process occurs naturally, without conscious intent, and often without conscious awareness of the nature of the prototype. New experiences are interpreted in light of their similarity to the underlying representation. Indeed, the prototype appears more familiar than any of the specific instances.

While much of the research on prototypes has used perceptual stimuli, more recent findings have shown that a similar mechanism underlies the formation of frames for interpreting commonplace events (the so-called scripts for restaurants fall into this category; also cf. Belezza & Bower, 1980, on "event" prototypes) and for linguistic patterns (the frames that underlie frequently occurring sentence patterns and story grammars are probably acquired in this manner; cf. Thorndyke & Hayes-Roth, 1979).

Researchers have suggested three interpretations for the findings on prototype formation (Anderson, Kline, & Beasley, 1979; Hintzman & Ludham, 1980; Medin & Schaffer, 1978). One theory is that the person creates an average, as it were, of all the instances that appear similar. You might imagine an equilateral triangle as the summary of your experiences with triangles. A second approach holds that the individual remembers selected instances from previous experience, and any new experience is compared with what is remembered to see if there is a reasonable match. The person might remember most of what has been encountered, or particular instances might be selected because they stand out, or because they seem to be "good" in some sense. A third proposal is that the person analyzes experiences into elementary features; experiences are similar insofar as they share common features and a prototype is simply a collection of features that occur together fairly often.

While the three models seem quite distinctive in their account of the process of abstraction, they yield similar predictions about observed behavior. All three give a reasonable account of the existing research, and it is possible that individuals use all three methods from time to time. The important result is that human beings tend to search for generalities and similarities in the experiences that they encounter. The processes of abstraction operate unconsciously, and the person is seldom able to articulate the distinctive features of a prototype with any clarity. No matter; as Bolinger (1980) puts it:

> This seeing of like and unlike, of putting together and classifying apart . . . is the mechanism through which reality is organized and the whole construct of language is built . . . The world is a vast elaborated *metaphor* . . . Nature does not come to the child in ordered fashion, but the child is equipped to perceive parts of it, and is born with one intellectual capacity that surpasses all others: the ability to see resemblances. (p. 191)

A second way to build frames is more formal and analytic and comes about largely through schooling and other educational experiences. When the student learns a *taxonomic system* ("animal, vegetable, mineral" is an example; more formal instances come readily to mind), or an *explicit grammar* (how to diagram sentences or to outline an expository passage), or a *mnemonic system* (the pegword system or the method of loci; see Bower, 1970; Yates, 1966) the student, in all these instances, is acquiring a frame with conscious intent and in a form that is widely shared by other individuals in the culture. Our examples are from Western "school" culture, but similar events can be found in many other settings. While these devices are generally taught with accompanying examples, the process of acquisition may be deductive rather than inductive. Unlike prototype formation, in which the individual abstracts a model that reflects the idiosyncracies of her or his particular experiences, formal frames are uniform and streamlined to ensure efficiency and consistency. A formal frame is more likely to be stored in memory as an entity in its own right. Such a formalism can be applied to a wide variety of situations, quite apart from the original accompanying content. To be sure, it may also become mentally encapsulated, so that it is relatively inaccessible and unusable.

In the best of circumstances, a frame is a formalized metaphor, a mental tool for tackling new problems and filling the gaps in everyday experience in an intelligent manner so that life becomes understandable and events are under our control. As Snow and Yalow (in press) remark, some individuals are better than others at taking advantage of metaphor, of analogy, of "family resemblance." Formal education has as one of its chief goals to train the student in the skills of metaphor and to make the student familiar with some of the more important analogies that come from science, history, and art. The dilemma in schooling is that the student cannot simply be taught the universe of frames that are judged to be important at any given time. Instruction must be to some degree incomplete, so that the student learns to search for principles on his or her own and to develop skills in the application of conceptual frameworks (Wittrock, 1978). Snow and Yalow note that,

> In education, intelligence is learning ability, in the sense that it is the active organization of abilities needed to learn from incomplete instruction, and to use what information may already be in the cognitive system, or can be induced therefrom, to help in doing this. (p. 36)

How are frames used in storage? Some of the earliest research on organization and memory suggested that structural frameworks were quite important when a person was recalling something, but were less essential during storage of information. This is a puzzling result. Common sense suggests that we understand and remember new experiences by relating them to familiar patterns. The early findings came from studies of the free recall of random word lists, and it now seems likely that for such simple materials it may not matter whether an organizing framework comes while the information is being studied or at the time it is being recalled.

More recent studies have shown that the memory for a large, complex, and relatively uncommon package of information may depend very much on the individual's success in finding an organizing framework while the material is being studied (Bower, 1976; Bransford & Johnson, 1972; Friedman, 1978; G. Mandler, 1972). The studies just referenced all investigated recall of large quantities of information that could be organized by familiar frames (stories and other commonplace occurrences). I suspect that the importance of frames is even more important in studying school subjects such as biology, physics, geology, and so on. A precise knowledge of the subject matter content is probably an essential prerequisite to formulating organizing frameworks in such instances. Ausubel's (1960) and Scandura's (1977) advance organizers are alternate ways of talking about frames; the uneven success of these research programs (cf. Luiten, Ames, & Ackerson, 1980) in demonstrating the effectiveness of their concepts may reflect a weakness in their methods for constructing frames rather than any deficiency in the basic proposals. In general, however, the existing data support the importance of frames in the storage of information. In addition, it may be important for the student to remember also the organizing framework itself, so that this structure is automatically called forth when he is being tested on the knowledge.

While my review of research in this area has been sketchy, I think that a more thorough-going examination would still leave us tantalized and far from satisfied. Human beings organize all attended experiences, and providing an explicit framework serves only to augment activities that are already ongoing. Organizing activities are essential to identifying the key elements in a complex stimulus; the individual must refer to some kind of framework when he parses a stimulus into coherent chunks. A frame of reference seems a reasonable device whenever an experience is stored in long-term memory. These comments are admittedly conjectural; I think we have yet to see definitive experiments on the effects of frame structure on the encoding and storage of information in long-term memory.

How are frames used in retrieval? Numerous studies have established the significant role of organizational frames when the individual is asked to retrieve a body of information from memory. In the typical experiment, a collection of disorganized "facts" is presented. The individual is then asked to reproduce the collection, either with or without a retrieval plan being provided. For instance, a subject studies a long list of words which can be arranged according to a set of taxonomic categories, but presented in random order so that the structure is obscured. Recall is very substantially improved if the category labels are provided as prompts during the recall phase (Cohen, 1963; Kintsch, 1968; Tulving & Pearlstone, 1966). Such labels are simple frames, to be sure, but they are nonetheless effective. The same effect can be found if the student is given cues at the time of recall, like the titles for episodes in a story (Bower, 1976, 1978; Owens, Black, & Bower, 1979) or a list of information types in an exposition (e.g., "Tell me about Jones' education? His government service? etc.", Bower, 1974). Research on story grammars has shown that students will revise a poorly formed story during recall so that it conforms to a "good" organization.

These bits and pieces of information are all consistent with the conclusion that recall of information is best if the student follows some kind of guiding framework, either one that he or she generates on his or her own at the time of recall, or that was stored as part of the original memory, or that is provided as part of the testing procedure.

Having an explicit framework during retrieval serves several functions. It makes it easier to search for information in memory so that a production test is more like a recognition test. The frame serves as a checklist, ensuring that the student searches through all the appropriate areas of memory in a systematic and comprehensive fashion. Finally, it provides a scheme for ordering and arranging the information properly, which is often an important criterion.

As noted earlier, prototypes (natural frames?) are a consequence of repeated experiences. In such instances, the frame is an inherent part of what is remembered and is likely to be called forth automatically during recall. For instance, children as young as 4 or 5 years of age possess a frame for stories (Applebee, 1978; Mandler & Johnson, 1977; Stein & Glenn, 1979). They are facile in creating stories of their own, and in retelling stories of others (however, cf. McNamee, 1979).

A student may have been taught an organizational structure and may even be able to reproduce it on demand. Whether the student will apply this knowledge during retrieval is another matter. If the frame has been associated with a range of experiences during training, it is more likely that the student will think of using the frame when a similar experience is encountered in a new setting. Students may also be trained to search for appropriate frames when they run into problems. The research on meta-memory points to the value of directed use of frames (Brown, in press; Brown & Deloache, 1978; Greeno, 1978b). For instance, preschool children seldom listen to a story with anything approaching an analytic framework. The result can be a rather superficial "in one ear and out the other" understanding. Explicit training can make the youngster consciously aware of the need to search for various story elements and to seek to comprehend the relations. This strategy, which goes beyond simply "listening for fun," is probably the first step in building a frame for "what it means to study."

Summary. If working memory operates in the fashion described above, then, as Greeno (1980) suggested, it is indeed fundamental to educational growth. In particular, the purposeful use of frames may be a critical adjunct that significantly enhances the potential of human thought. Research on metacognition bears on this issue, as does the line of work on "teaching thinking" that stretches from Vygotksy (1978) through Feuerstein (1980; also cf. Brown & Ferrara, in press; Snow, 1980a).

Pribram et al. (1974) suggested that memory operates like a hologram. The question remains, what is the source of "coherent light" in this metaphor, and how is it directed onto the subject of interest in memory? Formal, abstract frames may serve just this function. That is to say, the individual may learn to examine an experience from several perspectives by using frames as a guiding structure for analysis (Getzels, 1979; March, 1973; Pounds, 1969).

The process begins with instruction in formal approaches to thinking, generally in reading and mathematics. Once individuals have acquired the basic idea, they can apply it quite broadly (e.g., Resnick, 1976). It is at this point that cognition feeds back into itself to enhance the mind's potential. Brown (in press) presents this point in the following way:

> In the course of evolution, cognitive programs become more accessible to other units of the system, and can be used flexibly in a variety of situations. This flexibility is the hallmark of higher intelligence, reaching its zenith at the level of conscious control . . . over the full range of mental functioning. . . . Much of formal education is the process of gaining access to rule-based components already in the head, i.e., the process of coming to understand explicitly a system already used implicitly. (ms. pp. 26-27) (Brown refers to similar arguments by Rozin, 1976.)

A CONCEPTION OF EDUCATION

In this section, I want to examine how ideas from cognitive psychology can inform our conception of education and help improve the processes of schooling. Schools and other educational institutions serve various purposes in the society. Among these are the acquisition and maintenance of formalized knowledge, the development of individual intellects, and the sorting and selection of individuals for performing societal tasks that require intellectual competence (Snow & Yalow, in press). As society has become more complex, and with the press for universal schooling, the educational enterprise has fallen increasingly under scientific scrutiny. In particular, for more than a century psychologists have made it their business to study education, and along the way they have influenced the schools in various ways. Before presenting a cognitive perspective on education, I want to digress briefly to discuss the role of psychologists in education.

Contributions of psychology to education. Psychologists have made several contributions to education over the past several decades: the development of test theory and of instruments for standardized assessment of aptitude, knowledge, and ability; behavioral analyses of school subjects; and a vast array of empirical findings about teaching and learning (Farley & Gordon, 1981; Wittrock & Lumsdaine, 1977). Work goes on apace today in these fields, and cognitive psychologists have made their mark in fields as diverse as literacy (Resnick & Weaver, 1979, for a sample), mathematics (Gelman & Gallestel, 1978; Resnick & Ford, 1980), problem solving (see papers in Snow, Federico, & Montague, 1980, for recent examples and references to earlier work), teacher decision making (e.g., Shavelson & Stern, in press) and attitudes in social studies (e.g., N. H. Anderson, 1981).

This body of research represents a clear advance in our knowledge of educational phenomena, and yet it has a limitation. As other observers have noted (e.g., Grinder, 1981; Suppes, 1974), educational research by psychologists and other social scientists have been predominantly empirical, pragmatic, and atheoretical. Counterexamples to this generalization can be found, but they are rare (Atkinson, 1976; Bruner, 1966; Suppes, Macken, & Zanotti, 1978).

An applied science needs to stay in close touch with the realities of its companion field of practice. Nonetheless, to eschew theory altogether is to lack a roadmap for guidance; it is difficult to see in piecemeal facts a coherent whole. We wind up with large quantities of data of unknown validity and uncertain meaningfulness. Several scholars have questioned whether generalizable research on education is even possible (e.g., Campbell, 1974; Cronbach, 1975; McKeachie, 1974; Snow, 1977; Tom, 1980).

It appears to me that modern cognitive psychology may have its greatest impact on education not from empirical findings and microtheories, though these are important, but rather from an emerging set of notions about how to understand complex systems, notions that have resulted from analyses of intelligent thought and the creation of artificial intelligences. I now want to show how these analyses might provide theoretical guidelines for a more coherent conception of education and the processes of schooling.

A theory of the educated mind. How does schooling affect the mind? In considering this question, let us assume a conventional notion of the school as a formal setting in which teachers present classical academics across a broad array of curriculum domains.

Here is an answer that may at first seem overly simple, but which actually possesses great power: The effect of schooling is to create a set of well-organized mental structures that parallel the various curriculum programs, both those that are named (literacy, mathematics, science, physical education) and those that are implicit (self-discipline, responsibility, courtesy, competitiveness; cf. Dreeben, 1968). Thus, students who have been taught to *read* become the possessors of a complex "frame," if you will, which provides them a culturally designed and sanctioned tool for handling a set of tasks that are important for the society and for the individual. (Illich, 1973, gives an interesting though somewhat one-sided account of the problems of balancing the value of educational tools for the society and for the individual.)

Let me restate the thesis in a slightly different manner, using Figure 4 as a reference. The figure shows that certain elements in long-term memory are primarily experiential, natural, and untutored. In the educated person, however, one also finds elements that are the result of schooling, that reflect formal ideas and conventions, that emphasize consistency and efficiency, and that in many instances can be readily brought into consciousness for examination and reflection.

A point to be expanded on later in this section is the notion that when a person has been properly educated, when he has become a competent reader or writer, then the resulting mental structures operate as a set of *independent* (Calfee, 1976a; Frederiksen, 1980; R. J. Sternberg, 1977; S. Sternberg, 1969) or *"nearly decomposable"* (Simon, 1981) components.

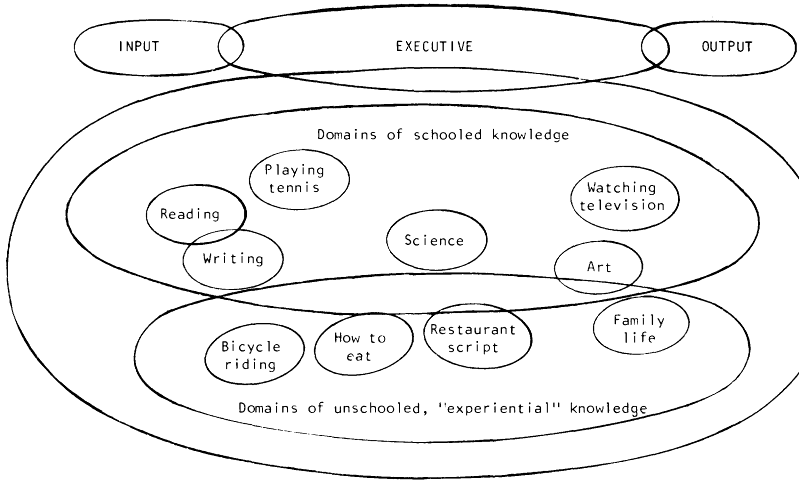


FIGURE 4. A model of the educated mind.

Simon (1981) makes the clearest argument. No complex system is likely to evolve or to maintain itself unless it is fashioned around a relatively small set of elements, each of which may have a complicated internal structure, but which are related in simple ways to one another. Infinitely interactive systems are inherently unstable, inefficient, unmanageable, and unpredictable.

The key to understanding and maintaining any complex system is to look for the "joints" that most efficiently divide it into a set of simpler systems. This principle works with all sorts of complex systems: biological, social, artificial (e.g., computers), psychological, and educational. I find the carving of a turkey to be a helpful metaphor. A turkey is rather complicated, and can pose quite a challenge when the novice undertakes to carve the beast on Thanksgiving. The trick is to know where the joints are. Then the carver can divide the bird into a small number of chunks that are relatively easy to handle.

In mastering a complex task—writing, auto mechanics, chess, biology—one can search for the underlying structure by trial and error. Indeed, much of what we learn informally comes from wrestling with unadorned, unanalyzed experience. But experience can be a hard teacher, and it is with good reason called the "school of hard knocks." Unguided experiential learning has the comfort of concreteness and the benefit of the immediate feedback, but it often yields little understanding and limited transfer. You can wreck a lot of roast turkeys before you find an approach that works, and you may never, as an individual, find out how to handle a turkey.

One can view the school as a repository of "maps" that lay out the joints in various complex systems important to our society, and a place where youngsters are introduced to these mysteries. (Bordieu, 1971, p. 194, refers to "master-patterns".) In the ideal case, the well-designed curriculum and the knowledgeable teacher bring together the accumulated cultural artifacts in a form that can be passed on to the next generation. These structures are neither complete nor perfect; there are gaps and mistakes. But they are the best that we know at the time, and they are the foundation for further advancement of societal knowledge.

Another perspective on the effects of education comes from discussions about the effects of literacy. Goody and Watt (1963; also Goody, 1977) trace the origins of this discussion to Plato and Aristotle. (For other recent accounts, cf. Calfee & Freedman, in preparation; Olson, 1977, 1980; Vygotsky, 1978.) An important distinction is drawn between oral language in natural settings and written language in formal settings. Related to this contrast is the degree to which a communication is explicit and context free. Informal conversation is elliptic; the discussants fill in what is unsaid through their shared knowledge of the situation. Formal texts are more complete; nothing important for comprehension is left unsaid. To be sure, the individual must know the procedures and conventions used to compose the text in the first place. A book is open only to the individual who is facile at decoding the orthography, who has sophisticated knowledge of vocabulary and grammar, who brings to the text a set of outlines or "macrostructures" that help organize the information, and who is aware of the importance of seeking for meaning in what he reads. These understandings are rarely the result of untutored experience or self-discovery; they are most likely to appear when the individual has undergone a planned program of instruction.

The surface distinctions between more or less formal styles of thought and communication are fairly apparent to the eye and ear (e.g., Chafe, in press). Word choice, sentence grammar, and the density of information differ between casual and planned speech. Less apparent but equally important is the difference in the underlying structure of knowledge. The untutored youngster is relatively free to create his or her own taxonomy of living beings, and may indeed fashion his or her own definition of "life." If experience leads the child to believe that whales are more like sharks than dogs, so be it. Natural, idiosyncratic prototypes may have more immediate practical value than the sophisticated taxonomy of the biologist, who claims from a deeper theoretical analysis that whales and dogs are more closely related. Nonetheless, educated persons are taught the accepted taxonomies, which reflect the structures (i.e., the "joints" in a system) as currently defined by scholars and sanctified by the society. Students also learn something about the reasoning behind the accepted structures, at least in the ideal case. The prototypes from naive experience may or may not be lost along the way, depending on their functional value and their conflict with the established "truth." And our truths are in continual change because the educational process is just that, a process of searching for simpler understandings, of finding ways to divide the complexities of the world so that we can see more clearly and can more fully control the environment.

THE CURRICULUM AND COGNITION

The curriculum of the school is the primary repository of our formal knowledge of the world. The curriculum is found partly in texts and syllabi. It is represented also in the understandings of the instructors who translate the texts for students. By analysis of the texts and of teachers' thoughts and actions, we discover the schema that are the basis for educational growth.

You might wonder whether the examination of the curriculum is a proper task for the cognitive psychologist. Let me turn the matter around and suggest that without having performed this analysis, cognitive psychologists will be stymied in the task of understanding how the mind works—at least they will have trouble understanding the minds of people who have been educated.

Greeno (1980), in concluding his retrospective on the last two decades in the psychology of learning, proposed that

> A pleasant prospect . . . now emerging is the revival of strong connections between the psychology of learning and the practice of instruction in schools. . . . A deep theoretical understanding of the psychological processes involved in school learning could become the keystone of a significant new psychological theory of learning. (p. 726)

I think that Greeno is on the right track. Let me press the argument further and suggest that a critical element in the psychology of school learning is an understanding of the environment of the school. Furthermore, what chiefly distinguishes this environment is that it is not accidental, but is carefully designed (in the ideal case) to achieve certain goals. To understand this design is to understand the curriculum.

The argument finds concrete expression in a fable:

> We watch an ant make his laborious way across a wind- and wave-molded beach. He moves ahead, angles to the right to ease his climb up a steep dunelet, detours around a pebble, stops for a moment to exchange information with a compatriot. Thus he makes his weaving, halting way back to his home. . . . I sketch the path on a piece of paper. It is a sequence of irregular, angular segments—not quite a random walk, for it has an underlying sense of direction, of aiming toward a goal.
>
> I show the unlabeled sketch to a friend. Whose path is it? An expert skier, perhaps, slaloming down a steep and somewhat rocky slope. Or a sloop, beating upwind in a channel dotted with islands or shoals. Perhaps it is a path in a more abstract space: the course of search of a student seeking the proof of a theorem in geometry.

> Whoever made the path, and in whatever space, why is it not straight; why does it not aim directly from its starting point to its goal? . . .
> Viewed as a geometric figure, the ant's path is irregular, complex, hard to describe. But its complexity is really a complexity in the surface of the beach, not a complexity in the ant. . . .
> An ant [and likewise a man], viewed as a behaving system, is quite simple. The apparent complexity of his behavior over time is largely a reflection of the complexity of the environment in which he finds himself. (Simon, 1981, pp. 63-65)

Few American psychologists of whatever persuasion have spent much time examining the environment and its effects on thought and behavior. Perhaps it was an impoverished definition of the "stimulus" that has led us to focus on limited and isolated facets of the external world. In any event, as Resnick (1981) has noted, American psychology has been dominated by two assumptions:

> 1. *The biological assumption*. . . . Psychology has been far more concerned with characterizing the nature of the human organism . . . than with characterizing the organism's environment, particularly its social environment or culture.
> 2. *The individualist assumption*. We have in American psychology assumed that differences among people can be understood as *individual* rather than *social* differences. (pp. 1-2)

Resnick thinks that these assumptions have shaped psychology's influence on education in this country in three ways:

> (a) an emphasis on "respecting" the course of children's development rather than shaping it, (b) a nearly complete absence of a theory of how environments, including educational environments, influence development, and (c) a mistrust of instruction as incapable of profoundly influencing human development. (p. 2)

That psychology need not adopt such a stance can be seen in the activist position of Russian psychologists, who for several decades have worked from assumptions that contrast quite sharply with those of American psychologists.

My chief concern in this section of the chapter is with Resnick's second point: the need for guiding principles that might lead us to a theory of curriculum, as one special instance of an important environment (also cf. Sanders, 1981; Shuell, 1980, p. 282; White et al., 1977). Just in passing, let me note that one can find a few other examples in American psychology where a concern with the environmental context has been central. Brunswik's (1956) representational design and Gibson's (1979; also cf. Haber, in press) analysis of the visual stimulus are two early instances. More recently, we find Bronfenbrenner (1976, esp. p. 173), Shulman (1970), and Snow (1974) talking about the experimental ecology of educational research, and Cole and his colleagues exploring the effects of the cultural context (including schooling) on thought and behavior (Scribner & Cole, 1978; Sharp, Cole, & Lave, 1979). But none of these analyses has focused on curriculum as a central issue. This task has fallen to scholars of quite different persuasions, and I want to turn next to their work.

A definition of curriculum. The listings in the school catalog, the entries on a scope-and-sequence chart, the materials prepared by a publisher to teach elementary science—all of these illustrate our common sense usage of curriculum. The word derives from the Latin *currere,* to run. The metaphor is the race track, the obstacle course, the cross-country layout.

In life outside school the pathways vary in random and unpredictable ways—Simon's ant traces a track that is partly direct, partly random, depending on the lay of the land and the obstacles encountered. In life inside school, the pathways are presumed to be laid out in a more orderly and systematic manner: "The curriculum . . . can be conceived of as a series of planned events that are intended to have educational consequences." (Eisner, 1979, p. 39). The tracks of youngsters along the curriculum should exhibit consistency and purposefulness, more so than the marks of an ant, a sailboat, or a skier. Dewey (1902), who seems at one time or another to have said everything worth saying about education, also used the terrain as an analogy to discuss the joining of structure and experience:

> The map is not a substitute for personal experience. The map does not take the place of actual journey. The logically formulated material of a science or branch of learning, of a study, is no substitute for the having of individual experiences. . . . But the map, a summary, an arranged and orderly view of previous experiences, serves as a guide to future experience. . . . Through the map every new traveler may get for his own journey the benefits of others' explorations without the waste of energy and loss of time involved in their wanderings. (pp. 20-21)

The curriculum is an *artifact,* as is the school. Teaching is *artifice,* and education itself is *artificial.* All three words are from the Latin *ars* (art) + *facere* (to make). Simon (1981), in his lectures on *The Sciences of the Artificial,* contrasts the study of natural phenomena and the study of man's creations. Biology, physics, and chemistry exemplify the natural domain; engineering, education, and "artificial intelligence" illustrate the second category.

Simon's distinction between the natural and the artificial provides a conceptual basis for the formal curriculum (Resnick, 1981, makes a similar point). Schooling is the tool created by man to transmit the capacity for rational, reflective thought and problem solving. As natural selection is the guiding force in evolutionary biology, so rationality provides direction in human social evolution. If Simon is correct in this proposition, and I think he is, then the school provides the chief alternative to survival of the fittest individual (e.g., it is the place where people can learn to play tit-for-tat in a principled way and understand the consequences; cf. Axelrod & Hamilton, 1981). Like any other instrument created by man, the school works best when fashioned according to a planful design, and when implemented by artisans who are knowledgeable about the underlying design and skilled in the use of the instrument.

Curriculum theory and curriculum design. Webster's Dictionary defines *design* as "a mental project or scheme in which means to an end are laid down." A design is a special instance of problem solving in which planfulness and guided thought predominate. In this section, I want first to review some present-day theories about curriculum design, and then present several principles consistent with cognitive psychology, which extend and fill out these theories.

The concept of *theory* covers a variety of organized thoughts. One ideal is found in the accounts of physical phenomena associated with Newton and Einstein. It is important to remember, however, that a curriculum is a work of man rather than a phenomenon of nature. As such, Hirst's (1971) advice seems appropriate:

> Theories of science and . . . theories of practical activities are radically different in character because they perform quite different functions; they are constructed to do different jobs. In the case of empirical sciences, a theory is a body of statements that have been subjected to empirical tests and which express our understanding of certain aspects of the physical world. . . . [For] a practical activity like education . . . the place of theory is totally different. It is not the end product of the pursuit, but rather it is constructed to determine and guide the activity. (p. 342)

Walker (in preparation) has proposed that a curriculum theory may presently serve any of four functions:

—It can be used to rationalize a particular instruction program;

—It can be used to rationalize a set of procedures for creating a set of curriculum programs;

—It can provide a conceptual basis for thinking about a curriculum;

—It can serve to explain curricular phenomena.

The first two functions address pragmatic issues, and the last two functions speak to intellectual and scholarly concerns. Whatever functions may be central in a particular curriculum theory, one generally finds that the theory itself comprises a grab bag of ideas and models from other disciplines, well larded with substantial amounts of unexamined common sense.

Practical theories always have an informal aspect, but the principles of curriculum design seem to be considerably less well articulated than models for design of the space shuttle or the Goldberg variations. That different sets of principles are often at work is clear. "DISTAR Reading" and "Man: A Course of Study" clearly seem to arise from different wellsprings. It is just that the nature of the differences is not always clear.

The benefits and dangers of a well-articulated, theoretical position for curriculum design have been contrasted by Walker (in preparation):

> Curriculum theory rationalizes, gives reasons, justifies courses of action. . . . It has the power

to persuade and to educate to a common view. Where there are differences, theory makes it possible to identify them, express them, and thus to work toward a resolution of them.

The dangers of theory arise from overdoing it; from refusing to temper theory with judgment; from fitting the situation to the theory rather than vice versa; from cynical, self-serving exploitation of theory's power to inspire masses of relatively uncritical practitioners; from attempting to base practice entirely on some narrow theory that neglects important elements in the situation.

It may appear presumptuous in this complex and politically charged arena to propose that findings from cognitive science will help. Nonetheless, a curriculum is a tool to be used by teachers for instructing students, the whole enterprise seeming preeminently cognitive. Accordingly, let me suggest four guiding principles from cognition that may serve as useful boundary conditions for curriculum design:

(1) Any complicated structure must be divided into a relatively small number of chunks in order to be understood.
(2) The chunks into which a structure is divided must possess a self-supporting, internal coherence.
(3) The most effective progression for acquiring a new structure begins with concrete examples, and after the student has become facile at handling a topic, the fullest extent of transfer is then achieved by helping the student gain a conscious understanding of the principles.
(4) Attaining expertise in any complicated domain happens over time—guidance comes as much from developmental psychology as from cognitive psychology and curriculum theory.

Limited capacity. The human mind can assimilate enormous quantities of information. There is a catch: the information must be divided into chunks, there must be a scheme for reconstructing the knowledge, the learner must be engaged with each chunk for a reasonable amount of time, and the learner must experience several variations of the information (assuming that anything worth learning is likely to vary in its specifics).

Man has a limited ability to process information, and this theme runs throughout cognitive research. Miller (1956) suggested the "magic number" was seven; G. Mandler's (1967) guess was closer to five; and Simon (1981) estimated the limit at two chunks (a disturbing trend?).

The limited-capacity principle is regularly disregarded by the designers of curriculum programs. On the one hand are programs that comprise so many detailed elements that it is difficult to imagine either teacher or student encompassing them (the skeptical reader might want to look over the scope-and-sequence chart for any contemporary reading or mathematics program (also cf. Bloom, Hastings, & Madaus, 1971; Mager, 1962). One can also find holistic models for the various subject matters, in which the discipline is presented as a single unanalyzed, and hence undigestible, whole (e.g., Reid, 1979).

Neither representation is well suited to the limited capacity of human information processing. In later sections I will give examples of more appropriate partitioning of selected curriculum domains.

Coherent chunks. If anything is to be remembered, it must be divided or decomposed into a number of "digestible" pieces. Moreover, the division cannot be arbitrary. The fundamental principle, as Simon (1981) demonstrates both analytically and by example, is to segment the structure into "nearly decomposable" pieces; the chunks should have the property that the interactions between chunks are relatively slight compared with the interactions within chunks. Simon refers to such chunks as *stable intermediate forms* (SIF). These are subsets of a larger system, which remain intact even when unattended. Taxonomies, schema, frames, all are devices of the mind that group together manageable amounts of information, which can then be set aside in memory while the student turns attention to another set of elements.

Goody's (1977) discussion of the effects of literacy can be understood in a different light by the SIF concept. Writing in its various forms—documents, books, lists, diagrams, tables, and so on—can be viewed as concrete realizations of SIFs. By arranging information in coherently organized packets (sentences, paragraphs, chapters, etc.), by transforming from audition to vision, the person has a greater range of choices for clustering the facts. Goody recounts how Margaret Masterman used her hospital bed to try different arrangements of a complicated set of concepts while planning a book. The newly emerging technology for "word-processing" (e.g., text editors and page editors) has considerable potential for the extension of organized thought, this potential being realized only as we can identify complementary techniques for teaching people to recognize the joints in the great mass of information that otherwise threatens to overwhelm us in the modern world.

Concrete to abstract. It is common knowledge that learning is easiest when the student is presented material that is familiar and concrete, both research and practice supporting this premise, which is scarcely the sole property of cognitive psychology:

> Lack of attention to the rhythm and character of mental growth is a main source of wooden futility in education. I think that Hegel was right when he analysed progress into three stages, which he called Thesis, Antithesis, and Synthesis; though for the purpose of application of his idea to educational theory I do not think that the names he gave are very happily suggestive. In relation to intellectual progress I would term them, the stage of romance, the stage of precision, and the stage of generalisation. (Whitehead, 1929, p. 2).

Similarly, one can find the advice in earlier psychologies of the importance of becoming facile at a task: practice makes perfect. Previously in this chapter I mentioned studies of information processing that provide important data on the mechanisms by which practice lessens the attentional demands of a task so that performance becomes automatic. The individual can then carry out the task "without thinking" and at the same time devote attention to other matters.

A distinctive contribution from cognitive psychology is a set of theoretical concepts and empirical findings that reestablish the importance of conscious understanding in learning. Techniques that rely totally on concrete, episodic events, without ever coming to a focus on the basic underlying principle, may add to the student's experience, but they leave her or him unable to extend the knowledge beyond the immediate circumstances of acquisition (Page, 1885, in Shulman & Keislar, 1966; Snow, 1980b). Indeed, instruction that emphasizes examples and leaves it up to the student to discover the significant generalizations will work only for that small proportion of students who, by personal inclination or previous education, seem always to search for, and often to come up with, deeper understandings (Cronbach & Snow, 1977; Heller & Greeno, 1979; Shulman & Keislar, 1966; Snow & Peterson, 1980).

Stressing the separability of curricular components is consistent with the role of meta-cognitive activities in learning and performance (Brown, 1978; Flavell, 1979). Meta-cognition (knowing what you know and how you know it) provides the finishing touches to an educational experience. Research shows that American youngsters are increasingly aware of their mental activities as they grow older (Hagen, Jongeward, & Kail, 1975; Kreutzer, Leonard, & Flavell, 1975), that they can learn in laboratory settings to gain meta-cognitive control over novel tasks (Brown, 1978; Brown, Campione, & Day, 1981), and that there is a correlation between the degree of meta-cognitive awareness and the level of performance on complex problem-solving tasks (Becker, 1975; Bobrow & Norman, 1975; Brown & Smiley, 1978).

Researchers are only beginning to explore the relation between meta-cognitive awareness and education, but the importance of this linkage seems clearcut (Brown, 1978, in press). Helping the student gain a broad perspective on the meaning of experiences so that this knowledge can be brought into play in other situations can be a powerful basis for transfer. Short-term, isolated experience may have little generalizability beyond the immediate circumstances of training, not even when the training is on meta-cognitive awareness! Brown (1978) compared the memorization performance of a group of students who had served in several of her meta-memory training studies with the skills of a second group who had not received such training. She found no discernible difference between the two groups.

The temporal dimension. Education is a developmental activity, and time is an important dimension in curriculum design. A review of a random sample of scope-and-sequence charts may lead to the conclusion that the designers are sensitive to the temporal dimension, and we have a few examples where sequential linkage have been examined quite closely (e.g., Gagné, 1968). In general, curriculum materials seem to follow a progression from the easy and familiar to the more difficult and abstract. The sequence is usually based on a relatively superficial analysis of the subject matter: basal reading series start with "simple" short stories fashioned from "simple" familiar words, and move toward longer stories and less common words. Length and word frequency are but two dimensions that affect the difficulty of a text, and there is reason to believe that the early primers may be far more challenging than is generally realized.

Time is but partly represented by the passage in the textbook from one page to the next. The curriculum covers days, weeks, years, and some of the most important aspects of the temporal dimension may entail the way that the curriculum is implemented over large blocks of time. We could use some closer examinations of the life span from preschool through high school and college. Both practitioners and researchers tend to look only at cross-sectional slices of this experience. For the youngster actually engaged in the "passage," the most critical determinants of success and failure are at the transitional points: from home to kindergarten, from primary to elementary, into junior high, and thence to high school. At each of these discontinuities the student is abruptly thrust into a new environment, too often with no forewarning and only happenstance support. The student's life must often seem a moment-to-moment collage. The rhythm of the week and the tolling of the class schedule are punctuated by the episodic moments so well captured in "Peanuts" by Charles Schulz, and expressed by other observers in only slightly less rhapsodic fashion (Ashton-Warner, 1963; Goodlad, Klein, & Assoc., 1970; Holt, 1967; Jackson, 1968).

For the teacher, planning spans days, weeks, and months. The year has a cycle, both curricularly and emotionally. Reports of the teacher's information-processing mechanism seldom reflect the fact, but early fall and late spring are altogether different from the hard times between Thanksgiving and Easter. Cycles turn within cycles (do not study a teacher's thoughts on Friday).

Change is a fundamental dimension of schooling, and the psychologist is constantly challenged to distinguish the effects of maturational development of learning through experiences outside the school walls from the educational growth that comes through formal instruction (cf. Oléron, 1977). Research is short sighted when it ignores the contextual effects of time, when it focuses on pretest and posttest to the neglect of the important events that intervene, or when it takes too limited a view of the evolutionary process. Similarly, curriculum design is incomplete when it attends to time in a superficial way, or when it focuses in too limited a way on moment-to-moment or day-to-day events. For instance, many scope-and-sequence charts in reading lay out the curriculum in an absurdly aggregative manner: once an objective is introduced, it is in the curriculum forever. Thus, by the late elementary grades, there are hundreds or thousands of objectives for both student and teacher. The processing load, if one takes the chart seriously, cannot be borne by either student or teacher. Fortunately, few people attend too seriously to the chart.

AN INFORMATION-PROCESSING ANALYSIS OF THE SCHOOL

What is the school, and is this a proper question for the cognitive psychologist? As to the latter question, schools are social organizations, and so fall within the purview of organizational disciplines like sociology. Nonetheless, schools are populated by people—students, teachers, and administrators—and psychologists have a legitimate interest in the thoughts and actions of these individuals. Moreover, as Scott (1981) has pointed out, social institutions like schools have many of the characteristics of an individual:

> The social structure of the modern society can no longer be described accurately as consisting only of relations among natural persons: our understanding must be stretched to include as well those relations between natural and corporate persons, and between corporate persons. In short, we must come to "the recognition that the society has changed over the past few centuries in the very structural elements of which it is composed" (Coleman, 1974, p. 13 in Scott, p. 7).

The school may be the smallest autonomous unit in the educational system: "It is the school that establishes the structure within which teachers and students must function, and that establishes a territory distinct from the rest of life" (Eisner, 1979, p. 280). Interactions among the various actors within the school can be quite strong, compared with the weaker interactions between schools, or between any one school and the central office. Today's schools may lack such internal coherence, but this is an altogether undesirable state of affairs.

In any event, I now want to propose an information-processing analysis of the school, as one attempt to answer the first question at the beginning of this section. School is a place where people live and work and think, and so it is reasonable to explore the mental structures that guide the various inhabitants of the schoolhouse. I will consider in turn the cognitive processes of the student, the teacher, and the principal, and will attempt to interrelate these various conceptions. The focus will be on reading, but the extension to other areas of the curriculum is fairly direct.

The Mind of the Skilled Reader

When viewed as a whole, the mind of a student who is reading fluently may appear incredibly complicated. The argument earlier in this chapter suggests that an information-processing model can help us locate the joints in this complex system. For this purpose I want to consider two tasks that can be performed by competent readers:

—They can read aloud with fluency, accuracy, and correct intonation.

—They can comprehend (i.e., restate or paraphrase) passages containing new and unfamiliar information.

In this section I will present cognitive models for these two tasks, the models building one upon the other. Both models, and indeed all the models to be discussed here, are *independent process* models. The concept of process independence, first propounded by S. Sternberg (1963, 1969), holds that the cognitive theorist, in postulating a process model for a task, has the responsibility to specify a set of factors that uniquely affect each process and a set of performance indicators that uniquely measure each process. Unless the theorist can state how the process operates to this level of detail, then the theory is at best an intuitive, heuristic account of the thinking that underlies performance.

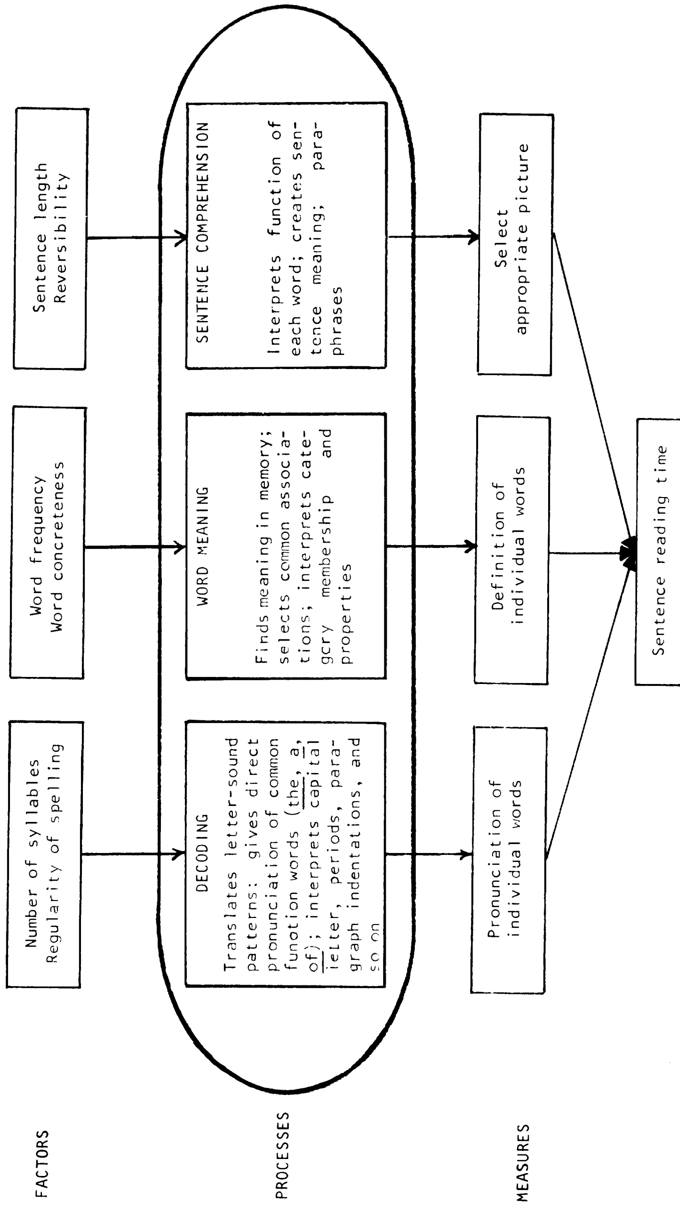
The independent-process concept leads to the development of formally testable models. The researcher can use the model to construct multifactor-multimeasure experiments. If the model is correct, then variation in the factors associated with a process should affect only those indicators associated with the process (Calfee & Hedges, 1980; S. Sternberg, 1969). If there is "cross-talk" between factors and measures, then the model is incorrect, at least for some of the individuals being studied.

The independent process concept is illustrated by studies of my colleagues and me on the mental components in skilled, oral reading (Calfee & Spector, 1981; Juel, 1977; Mason, 1977). Figure 5 is a model for the oral reading task. For each component, the nature of the process is briefly described, along with a factor set and a measure set. The independent components identified in the figure are closely associated with separable elements in the primary reading curriculum.

Our studies to date suggest that more capable readers perform pretty much as predicted by the model, decoding, vocabulary, and grammar each responding to distinctive factors. Less capable readers react in a more complex and interactive fashion: they appear to think in a complicated way while they are reading, and they do not read very well. Lesgold and Curtis (1980) have reported similar findings, using a different methodology.

These findings point up one way in which schooling may fail a student: if a youngster is presented a confused and muddled version of a curriculum domain, then understanding of the task may be confused and muddled. To be sure, we do not have direct evidence in our work (nor do Lesgold and Curtis) that the instructional program is directly responsible for the students' state of mind. Nonetheless, this proposition seems a good starting point, there being increasing evidence to suggest that students learn what

FIGURE 5. Application of independent process approach to a sentence reading task study (after Calfee & Spector, 1981).



they are taught (e.g., Walker & Shaffarzick, 1974). It also seems a plausible hypothesis that students will also understand clearly what they are taught clearly.

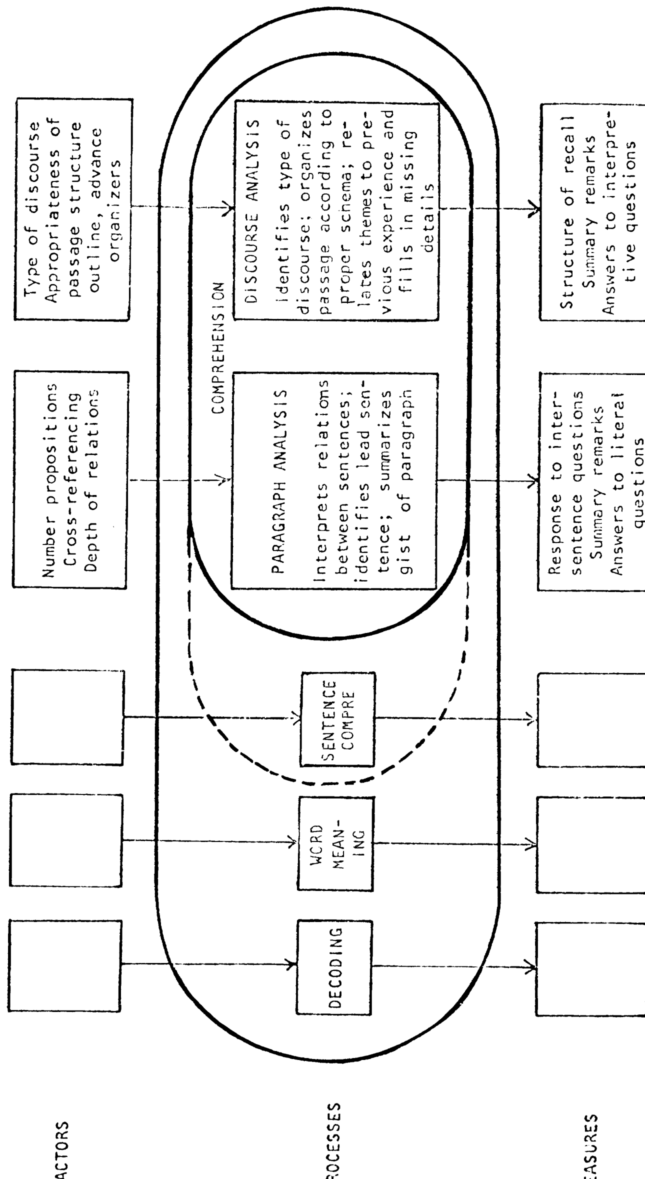
Turning next to the task of comprehension, you can find two distinctive approaches to understanding this task; both are fairly complicated. On the one hand are the behavioral objectives found in scope-and-sequence charts under the heading of *comprehension*. These include such entries as "main ideas," "literal detail," "interpretation," "fact versus opinion," and so on. Curriculum objectives of this type tend to be driven by a matching set of test objectives, which are often tightly and narrowly defined (e.g., Popham, 1981, esp. pp. 223ff). Complexity arises here because of the number of elements and the lack of coherence within and between elements. On the other hand is the work of cognitive psychologists on the propositional analysis of texts (e.g., Kintsch & Van Dijk, 1978; Meyer, 1975a, 1975b; also papers in Spiro, Bruce, & Brewer, 1980). These studies began with extraordinarily detailed examinations of prose (indeed, it was not unusual for some of the early exegeses to be longer by an order of magnitude than the texts which they sought to explain). In one sense this result might be expected. In the absence of formal theories of text structure there was a need to "dive in" and explore the richness of the stimulus. If one's goal is a simple understanding of text structure, however, it is important to avoid becoming enthralled by filamentous networks.

Taking a cue from rhetoric (cf. Ong, 1971), we have proposed the independent process model in Figure 6, which builds upon the model of oral reading and adds two processes: *paragraph comprehension* and *text comprehension*. Why these two components? Because they are visually separable in printed text and because they follow different paths to understanding.

A well-constructed paragraph comprises a single idea, generally introduced in the opening topic sentence and then elaborated by a few supporting sentences. The reader's task in comprehending a paragraph is to pick out the main idea and figure out the linkages among the supporting detail. Untangling a paragraph is what some psychologists have referred to as a "bottom-up" approach: the reader examines each proposition, works out the relation to what has already been said, and much like building a Tinkertoy, fashions an organized structure (Clark & Haviland, 1977; Rumelhart, 1975).

A student can read a passage, understand every word, every sentence, and every paragraph, and still have no idea about the overall meaning of the passage. This statement may seem unbelievable, but the evidence is clear (e.g., Bransford & Johnson, 1972; also, think about government documents that you have read). A text is a set of partial ideas that have been joined into a coherent whole. The distinguishing feature of a text is not its length, but its

FIGURE 6. Independent process model of comprehension.



sufficiency. Sentences and paragraphs are not usually designed to be fully understood in isolation; they cannot stand alone, but a text can. The reader's task is to recall or reconstruct a framework for organizing the various pieces of information. The amount of information is generally so extensive that the reader will be overwhelmed if he or she attempts the Tinkertoy method. Instead, the reader needs to employ a "top-down" approach: using what he or she has learned about the way in which texts are written, the reader needs to begin as soon as possible to formulate an hypothesis about the overall structure of the text. As new information comes in, he or she may decide to revise the hypothesis, or even scrap it and construct a new one. In any event, the comprehension of the text as a whole is driven through an active interpretation by the reader (cf. Calfee & Curley, in press, for one account; also Brewer, 1980).

I now leave the mind of the reader. Clearly a great deal more could be said about the system, which comprises just one of the facets in the mental apparatus of an educated person, just one of the boxes in Figure 3. The intention has not been to review cognitive research on reading, but to illustrate the application of independent process concepts to an important area of the student's education, and to demonstrate the close links between cognitive processes and curriculum elements.

The Mind of the Teacher

In the past 5 years, several studies have explored the cognitive basis for teaching (for reviews, see Clark & Yinger, 1977; Shavelson & Stern, in press). Much of this work, especially the studies from the Institute for Research on Teaching, springs from previous investigations on problem solving and decision making in clinical settings (e.g., by physicians, Elstein, Shulman, & Sprafka, 1978). It is founded on the assumption, congenial to the cognitive psychologist, and plainly stated by Clark and Yinger, that "what teachers do is affected by what they think." To delve into teachers' thoughts, researchers have employed self-reports, interviews, and "thinking aloud" techniques. The work has entailed small samples, ethnographic methods, and qualitative forms of analysis. The theoretical foundations are normative; what would a rational decision maker do under the circumstances, if such can be determined? The experimental method is generally eschewed; naturally occurring variations serve as a basis for judging the relative effectiveness of different instructional approaches (however, cf. Shavelson, Cadwell, & Izu, 1977).

Several generalizations about teachers' thinking have emerged from this research. First, it is clear that teachers seldom act as rational decision makers. But neither do most people. Second, teachers focus on materials and activities and other surface indicators of how the students respond to instruction. Third, teachers give little thought to curricular objectives or curricular structures other than the representations found in curriculum guides and teachers' manuals (e.g., Duffy, 1977; Floden et al., 1981).

These findings are brief, tentative, and troubling. As Clark and Yinger (1977) note, "at this time, we know very little about why teachers plan, how teacher planning changes with experience, and [about] individual difference variance" (p. 300). Indeed, much remains to be learned about the mental foundations that guide the teachers' actions in the classroom. (Shavelson and Stern [in press] have pointed out some promising directions for such work.)

Teaching is a task, and so it is reasonable to consider the independent processes that might enter into the thinking of a competent teacher. Figure 7 is a model proposed by John Shefelbine and myself (Calfee & Shefelbine, in press). If the model is correct, then factors and measures corresponding to each of the independent processes should be linked as discussed earlier in the chapter. These components comprise the rational basis for action by the teacher; to be sure, teaching is a profession and like other professions entails both reason and art (Eisner, 1979.) The model might also serve as the basis for a well-designed curriculum for teacher education.

A few words about each process, proceeding from left to right. If my statements sound normative and prescriptive, remember that the propositions are theoretical, and are intended as prescriptions. The teacher's conception of the learner was not included in our original proposal. We took it for granted! The nature of the student, the role of the school, the influence of contextual factors on the growth of the child—all would seem important for instruction. Unfortunately, when conceptions of development and learning and education are intermingled during a class in introductory educational psychology, one should not be surprised if teachers become confused and choose to ignore the topic during an interview.

The second process addresses the teacher's mental representation of a particular curriculum, and the understanding of how to translate this knowledge into objectives appropriate to a specific instance. The teacher of reading, for instance, should have a conception of literacy comparable to the one described in the preceding section. Whether the teacher chooses to focus on decoding or comprehension (a common controversy nowadays) is irrelevant. The informed teacher would have a knowledge of the overarching structure of a curriculum domain, which can serve as a guide for focusing on specific components when the situation calls for it.

Third is the teacher's understanding of principles for developing and selecting materials and activities. Publishers today provide systems designed to relieve the teacher of this burden. It is my belief, though without a great deal of hard evidence to support the position, that this approach will ultimately prove untenable and impractical. On the negative side, I doubt that "teacher-proof" materials and activities can be created. On the positive

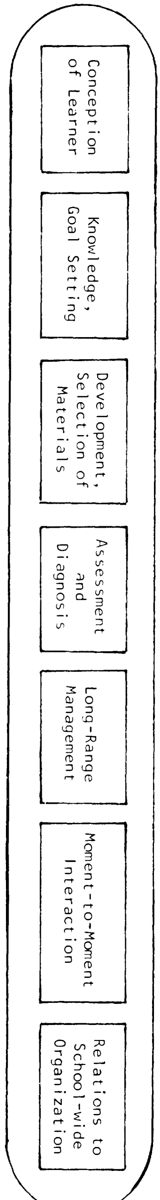


FIGURE 7. Independent processes comprising the rational basis for action by the teacher.

side, the teacher who has a principled understanding of the concepts and issues will be able to educate students whether on a desert island or in the midst of a multitude of workbooks and teachers' manuals. In fact, one can imagine a world in which the teacher's manual is designed as a device for enhancing the teacher's pedagogical knowledge rather than a script to be followed blindly (Smith, 1965).

Management refers to classroom planning that spans days, weeks, and months. It includes decisions about how to present the various materials and activities, and how to allocate time and energy to different segments of the curriculum. It covers the physical layout of the room, arrangements for grouping students into instructional units, and the development of routines for daily activities. The teacher operates a small business. As soon as class size is greater than a handful of students, management is essential to a smooth-running enterprise (Duke, 1979).

The extent to which students behave well and work at learning depends on the teacher's management skills, but also on how the teacher handles moment-to-moment interactions. Sue needs help in solving an anagram problem. Roger gives a partly right answer to a question. The geometry class registers puzzlement at the formula on the board. The boys in the "block corner" of the kindergarten are on the verge of a battle-royal. Hunter (1979) emphasizes the role of spontaneity for handling the decisions that confront the teacher during every passing moment: "[in many instances] there is no predetermined correct answer. The teacher must make a decision on his/her feet" (pp. 62-63). The importance of principled choices has been stressed by observers (e.g., Kounin, 1970). There is confusion of advice in these two perspectives. The teachers' thoughts about how to handle moment-to-moment choices may be guided by intuition, experience, chance, emotion, or by thoughtful and preplanned routines. Behavior modification strategies illustrate a more planful approach. The decision of how to respond to student behavior is dictated by a systematic analysis of response contingencies, and a knowledge of general principles of behavior change (e.g., Thoresen, 1973). I think that teachers should be thoughtful about handling moment-to-moment interactions for two reasons: (1) the methods are more effective, and (2) they provide the student with a model for how to deal with similar problems, in school and out, as child and as adult.

The final process on our list is the teacher's conception of the school as a social organization, and of his or her place within that organization. In the model as originally proposed, we made no reference to this component of teacher thought. Small wonder, since impressions from both research and practice suggested that teachers do not generally think of their relation to the school, a point to be explored more fully in the following section.

The model of the teacher's mind presented above may strike you as rather curious. At first glance it may seem "noncognitive". Matters like management and interaction might not seem properly designated as contents of the mind. Nonetheless, I find the model quite reasonable, given the earlier discussion on the structure of the educated mind. The seven components proposed as the basis for a competent teacher all seem essential, they are differentiable from one another, and they seem proper topics for a teacher education program. Incidentally, there is considerable overlap between this model and Kerr's (1981) philosophical analysis of teaching:

> First from our understanding of teaching as actions intended to encourage *persons* to *learn* things, we see that the *nature of the subject matter* to be learned, the *nature of learning,* the *nature of the particular learner* or learners, and the *nature of available means and resources* for encouraging persons to learn particular things constitute part of the relevant considerations of teaching actions. (p. 79)

The independent-processing model of teaching is chiefly of value insofar as it provides a framework for assessing and for training teachers. The clearest evidence on teachers' conceptions of their roles might well come from a structured interview (cf. Calfee & Shefelbine, in press). One might expect teachers, when asked to explain their conceptions of classroom instruction, to come forth with an explanation organized like the model in Figure 7, or some reasonable facsimile. To the extent that the model gives a plausible account of the thinking of a competent teacher, it provides an interesting challenge to cognitive psychologists (including myself) in the education of teachers. To paraphrase Walter Dearborn's advice to Bronfenbrenner (1976, p. 164), "If you think you understand something, try to change it."

By way of contrast, let me mention other "noncognitive" efforts over the past few decades to improve teaching performance. Some of these efforts are research based (see Gage, 1978; Peterson & Walberg, 1979, for recent reviews). The investigations have tended to be empirical, behavioral, correlational, and prescriptive; the typical study lacks theoretical foundation, focuses on action more than thought, entails interventions that are poorly controlled, yet eventuates in advice to the teacher on how to conduct classroom instruction (cf. Gage & Giaconia, 1981). The findings from this research are of descriptive value, and the studies demonstrate that teacher behavior can be changed, at least in the short run, and that student achievement can be enhanced, at least to a slight extent.

Tom (1980) has criticized this line of research, arguing that it is based on two questionable assumptions: "(1) Educational phenomena are natural, and (2) there is one best solution for any teaching problem" (p. 19). I am generally sympathetic with Tom's caveats and with his general conclusion: "[The role of research in teacher education is] to introduce new perspectives for viewing educational phenomena and to legitimize or critique educational movements" (p. 26).

Today's "practical" advice to teachers and to teacher educators is often piecemeal and incoherent, even when it emerges under the rubric of an information-processing approach (cf. Eggen, Kauchak, & Harder, 1979; Friedman, Brinlee, & Hayes, 1980). An important advance in research and practice in teacher education, both for assessment and for training, would be the development of a simple and coherent framework for classroom teaching: there may be many ways to "do it," but I suspect that a single conception will suffice for "thinking about it."

The Mind of the Principal

It may seem pointless to inquire into the cognitive processes of "principaling." Accounts of the school administrator's daily existence reveal a scene of frantic and stressful activity. Listen to this description by Blumberg and Greenfield (1980):

> Most aspirants . . . have only a vague understanding of much that [the principal's role] entails . . . the loneliness, the conflict, the dullness of the routine, the "busy work," and the anguish that accompany having to solve complex educational and organizational problems with limited resources. . . . (pp. 9, 10)
>
> While principals themselves may aspire to the traditional ideas of a principal as instructional leader, most find themselves besieged on a daily basis with the nitty-gritty administrative tasks involved in keeping the ship on an even keel, in maintaining the existing order in their school. (p. 24).

The Brownian movement within the principal's mind might warrant the attention of a clinical psychologist, but the phenomenon appears remote from the interests of most cognitively oriented investigators. Nonetheless, I see the area as a fertile ground for theoretical analysis.

It is clear that principals play a significant role in the school's effectiveness. McLaughlin and Marsh (1978) give the following account:

> The attitude of the principal was critical to the long-term results of a change-agent project. . . . One way in which principals demonstrated their active support for project activities—as well as gained the information necessary to promote continuation of project activities—was to participate in the project training sessions. . . .
>
> The attendance of principals . . . imparted some important messages to teachers—notably their personal commitment and their view that everyone was expected to cooperate and work hard. (pp. 81-82)

You will notice that the emphasis is on the principal's attitudes and personal involvement, and less importance is attributed to intellectual leadership (also cf. Lehming & Kane, 1981).

What is the principal's task? The role is a relatively new one. It was in the early 1900s that the "principal teacher" was gradually transformed into the principal, assuming along the way the responsibilities of school management, instructional supervision, and community relations (Blumberg &

Greenfield, 1980; also, cf. Tyack, 1974). Over the past 50 years the task has increased in size and complexity; schools are larger, demands for service are greater, and margins for error smaller.

School administration takes its conceptual base from several sources. An early influence was the field of scientific management. Thorndike (1910), Taylor (1947), and other proponents of detailed analysis of the workplace provided one set of ideas about the role of the principal. But school is not really an assembly line, and the metaphor has not proven apt. The striving for precise behavioral control continues to arise from time to time; witness the competency-based teaching movement of the past decade, and the emerging emphasis on engaged academic learning time (Denham & Lieberman, 1980).

The principal's role also has some features of the Weberian bureaucrat. That is, the school organization may be characterized by:

> A fixed division of labor among participants
> A hierarchy of offices
> A set of rules which govern performance
> A separation of personal from official property and rights
> Selection of personnel on the basis of technical qualification
> Employment viewed as a career by participants
> (Scott, 1981, p. 68)

The match with the bureaucratic model is seldom a close one. Teachers function not as coordinated workers acting in concert, but as "small batch" operators: "[each] teacher has responsibility for total production within the classroom including planning, operating and evaluating" (Blumberg & Greenfield, 1980, p. 242). The product of the school is not all that well defined. Principals may have the appearance of rational-legal authority, but careful observation reveals that they actually rely mostly on tradition (the tribal chief or father figure) and charisma (Blumberg & Greenfield, 1980, pp. 243 ff; Scott, 1981, p. 70).

Perhaps because of the absence of a clearcut conception of their roles, principals are often in conflict about the goals of the school. What is to be their position on contradictions like these?

—Stability and maintenance of the tradition, versus preparation for change and a predictably uncertain future.

—Management based on efficiency and "costwiseness," versus the experimentally inclined risk-taking inherent in educational leadership.

—Sensitive attention to the problems that emerge every moment of every day, versus reflective consideration of the long-range direction of the school.

There is some irony in the contrast between the school as a model of the coherent and self-maintaining organizations that we rely on as a basis for our societal well being (Scott, 1981, p. 79ff), versus the incoherent and occasionally self-destructive collectivity that one finds with some frequency today. Schools have been described by sociologists as "loosely coupled" (Meyer & Rowan, 1977; Scott, 1981, p. 107ff; Weick, 1974), which is one way of saying that the faculty operates relatively independently from one another. In particular, there is often a sense that no one talks to anyone else about professional matters. "Teachers can do what is expected of them, for the most part, without ever communicating with one another" (Blumberg & Greenfield, 1980, p. 242). March and Simon (1958) propose that the frequency of interpersonal interactions among members of a group is an

TABLE I
What a Principal Should Know How to Do

California Legislative Committee	Teacher Corps	Association of California School Administrators
Human Relations	Functions of advisory groups	Opening of School
Community	Goals and structure of the school	Know your school plant
School climate	The process of change	Know your opening needs
Communications	Managing time	Know your programs
Instructional Leadership	Setting priorities	Know your staff organization and needs
Student needs	Coordinating resources	Know your students
Instructional models	Communicating with others	Know your master calendar
Learning theories	Taking initiative	Contract Management
Supervision	Planning	Some do's and don't's
Personnel evaluation	Assessing needs	Managing Instructional Program
Program evaluation	Reaching consensus	Managing School Budget
Self-awareness	Tolerating stress	Managing Categorical Aid Programs
Self-assessment	Delegating authority	Establishing the school site council
Personal stress management	Collaboration	Managing Support Services
Personal time management	Power and authority within the school	Food services
Self-motivation	Relationships within the school	Transportaion
Political and Cultural Awareness	Relationships between the school and community	Custodial and building maintenance
Political		Managing School Climate
Cultural awareness		Staff
Strategies		Community
		Students
		Public relations
		Self-management
		Self-renewal
		How to say "no"
		Decision making
		Handling Emergencies

index of the strength of group identification. It is not far off the mark to suggest that the principal has the absurd task of trying to lead a nonorganization! (As an aside, Bronfenbrenner [1976, p. 199] has suggested that American society may be decoupled. I share his concern.)

Under these circumstances, it is perhaps not surprising that most principals (even effective ones) lack a conceptual framework. Their's is a "knee-jerk" existence, each moment calling forth a response based on whatever thoughts recent experience turns up. Principals are practical, antitheoretical, and frequently antiuniversity. Their training (if any), provides little help. The school of hard knocks is tough, but the alternatives are worse.

To illustrate this last point, I have assembled in Table I lists prepared by three groups: a legislative committee, a university-based, in-service training group, and a professional organization for school administrators. The lists contain recommendations about what principals should "know." Let me make a few observations about these lists. First, despite the overlap from one list to another, there are no overarching concepts. The "joints" are not obvious. Second, the lists differ markedly in the relative weight given to various domains, and in the way the domains are listed. Finally, there is no clear relation to the program of curriculum and instruction that is the primary task of schooling.

My natural inclination at this point is to suggest a set of independent components that should serve the principal in thinking about his or her task. The set in Figure 8 should be viewed as illustrative—it comes closest to Manger's (1978) conceptualization. As is true of any independent process structure, the model is testable if one can specify factors and measures for each process. It would be fairly straightforward to design a structural interview incorporating these elements that would provide a test of the model, and also serve for assessment of principal's conceptions of their task. In addition, the elements in Figure 8 provide a basis for a training program. The earlier discussions about reading and teaching provide the framework for helping principals think about their responsibilities for curriculum and instructions, and there might be considerable payoff in the development of shared conceptions by principal, teacher, and eventually the student.

I trust that this brief discussion shows how the analysis of the intellectual underpinnings of the principal's role might be a legitimate task for a cognitive psychologist. (It is interesting to note that not one paper on cognition is to be found in the extensive collection by Summer & O'Connell [1973] on the "managerial mind.") It also seems reasonable for the psychologist to roll up his or her sleeves and tackle the pragmatics of helping the principal. In fact, the practical aspects of this task may be the key to a workable theory. I resonate to March's (1978) words of advice on the design of a training program for principals:

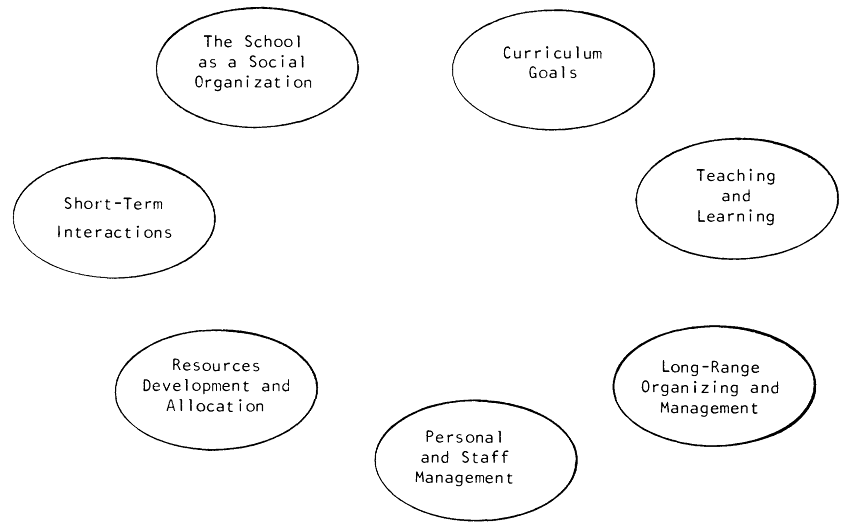


FIGURE 8. Set of independent components for the principal.

> [E]ducational administration is a bus schedule with footnotes by Kierkegaard. It involves the rudimentary pragmatics of making organizations work—laws, rules, logistics, therapy; complicated questions of inference, the interpretation of information, and the invention and justification of action; subtle literary and philosophic issues of human meaning; constructive criticism of daily events as art. . . .
>
> Consequently, designing a program for educational administrators [must] provide three things: a detailed encyclopedia of quick answers to the common questions arising in daily life . . . a handful of basic analytical models for trouble shooting problems . . . and a point of view about the whole process that communicates the considerable indeterminacy in outcomes, the necessary arbitrariness of . . . role performance, and the importance of relaxed commitment to doing the best you can. (pp. 244-245)

DIRECTIONS FOR THE NEXT TWO DECADES

We have learned much about cognitive science in the past quarter century, and a great deal of that knowledge is relevant to or rooted in the field of educational practice. While the way ahead is likely to be uneven for both domains, both will see substantial progress in the next two decades, partly as they join together. In this closing section, I want to reiterate a few themes that have arisen during this review and that seem to provide guidance for the future.

In a paper that I suspect is unknown to many psychologists, Shulman (1974) gives a brief history of the psychology of school subjects, during which he observes that "the time has come for a renaissance of a modern form of the psychology of school subjects . . . the parameters of that domain are already definable" (p. 326). In Simon's metaphor, Shulman seems to be saying "it's time to hit the beach," and I agree. How well the "parameters are defined" is another question; the current generation of cognitive psychologists has a lot to learn about the design and analysis of curriculum. Whatever the case, the careful examination of curriculum materials and instructional activities—examples of which are appearing in many places—will provide a clearer understanding of the educated mind, along with tools for investigating the cognitive potential of that mind.

For the second point, I turn again to Shulman (1974) for my text:

> [T]he proper scope for educational theory lies in what Merton (1967) has called "theories of the middle range." . . . a proper function of theory is to help us understand or render meaningful the phenomena of education we observe. . . . In the absence of such theories, intelligent instructional development and evaluative research become difficult, if not impossible. A set of theoretical concepts is needed to answer such questions as: How many dependent measures should we assess in the evaluation? What are likely to be the relevant outcomes. . . .? . . . Which [intervening] events are worth monitoring? . . . [Middle-range theory] ought to represent a marriage of the theorist's armchair and systematic empirical reality testing. (pp. 330-331)

This advice seems sound, and the mandate feasible. As Suppes (1974) pointed out several years ago, educational researchers have made little use of the theoretical tools at their disposal. The field is persistently empirical. In fact, the "unreal" tasks of the laboratory may have posed a greater challenge to subject and to experimenter than would the study of the "world of *real* people using *real* knowledge to solve *real* problems" (Shulman, 1974, p. 326). On the other hand, cognitive scientists seem to engage in overkill: highly sophisticated theory is brought to bear on the performance of trivial tasks in unrealistic situations. Nonetheless, scattered throughout this review have been instances of cognitive scientists tackling problems of genuine educational importance, and with considerable success. Norman (1977) expresses this new direction for cognitive psychology in his own refreshing style:

> I do not care about simple learning. I am not interested in the kind of learning that only takes 30 minutes. I want to understand real learning, the kind we all do during the course of our lives, the kind of learning that takes years to accomplish and that may, indeed, never be completed. (p. 39)

The third theme speaks to an informed and creative use of the impressive methodology that is the heritage of the last half century of psychological research (Calfee, 1976b). The tools are numerous, ranging from the quantitative armamentarium of psychometricians and experimentalists, through the midrange of structured interviews and computer simulations, to the qualitative methods of "thick" description and ethnographic observation. The list is not exhaustive nor are these devices the sole property of psychologists. Arguments about the appropriateness of various methods can be found in the literature; if ours were a pure and natural science we might expect a resolution of these arguments, but education will always call for many methods.

Education (and perhaps all of psychology) is an applied and artificial science. The questions are multifaceted and hence require a variety of approaches for their solution. I find myself turning again to Simon (1981), to his reflections on the "science of design" and his call for the strengthening of the professional schools as centers for design:

> [E]veryone designs who devises courses of action aimed at changing existing situations into preferred ones. . . . Design, so construed, is the core of all professional training; it is the principal mark that distinguishes the professions from the sciences. . . .
>
> In view of the key role of design in professional activity, it is ironic that in this century the natural sciences have almost driven the sciences of the artificial from professional school curricula. . . .
>
> [T]he older kind of professional school did not know how to educate for professional design at an intellectual level appropriate to a university; the newer kind of school has nearly abdicated responsibility for training in the core professional skill. Thus we are faced with a problem of devising a professional school that can attain two objectives simultaneously: education in both artificial and natural science at a high intellectual level. . . .
>
> [A] science of artificial phenomena is always in imminent danger of dissolving and vanishing. The peculiar properties of the artifact lie on the thin interface between the natural laws within it and the natural laws without. . . .
>
> The artificial world is centered precisely on this interface between the inner and outer environment; it is concerned with attaining goals by adapting the former to the latter. The proper study of those who are concerned with the artificial is the way in which that adaptation of means to environments is brought about—and central to that is the process of design itself. The professional schools will resume their professional responsibilities just to the degree that they can discover a science of design, a body of intellectually tough, analytic, partly formalizable, partly empirical, teachable doctrine about the design process. (pp. 129-132)

Dewey (1900; cf. Glaser, 1976) wrote in much the same vein at the turn of the century. Progress seems so slow, and this glance backward over the past 25 years gives the impression that, despite enormous effort, we have much yet to learn. Such may be the human condition. Let Marlowe (1955), who died before Newton was born, pronounce the benediction of hope for this passing moment:

> Nature that fram'd us of four elements, warring within our breasts for regiment, doth teach us all to have aspiring minds: Our souls, whose faculties can comprehend the wondrous Architecture of the world: And measure every wand'ring planet's course, and always moving as the restless Spheres, will us to wear ourselves and never rest, until we reach the ripest fruit of all, that perfect bliss and sole felicity, the sweet fruition of an earthly crown.

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