Issues in Cognitive Psychology: Implications for Professional Education

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ABSTRACT

Education and cognitive psychology have tended to pursue parallel rather than overlapping paths. Yet there is, or should be, considerable common ground, since both have major interests in learning and memory. This paper presents a number of topics in cognitive psychology, summarizes the findings in the field, and explores the implications for teaching and learning.

The organization of long-term memory. The acquisition of expertise in an area can be characterized by the development of idiosyncratic memory structures called semantic networks, which are meaningful sets of connections among abstract concepts and/or specific experiences. Information (such as the assumptions and hypotheses that are necessary to diagnose and manage cases) is retrieved through the activation of these networks. Thus, when teaching, new information must be embedded meaningfully in relevant, previously existing knowledge to ensure that it will be retrievable when necessary.

Influences on storage and retrieval from memory. A wide variety of variables affect the capacity to store and retrieve information from memory, including meaning, the context and manner in which information is learned, and relevant practice in retrieval. Educational strategies must, therefore, be directed at three goals—to enhance meaning, to reduce dependence on context, and to provide repeated relevant practice in retrieving information.

Problem solving and transfer. Much of the development of expertise involves the transition from using general problem-solving routines to using specialized knowledge that reduces the need for classic "problem solving." Two manifestations of this specialized knowledge are the use of analogy and the specialization of general routines in specific domains. To develop these specialized forms of knowledge, the learner must have extensive practice in using relevant problem-solving routines and in identifying the situations in which a particular routine is likely to be useful.

Concept formation. Experts possess both abstract prototypical information about categories and an extensive set of separate, specific examples of categories, which have been obtained through individual experience. Both these sources of information are used in categorization and diagnostic classifications. Thus, it is important for educators to be aware that experience with sample cases is not just an opportunity to apply and practice the rules "at the end of the chapter." Instead, experience with cases provides an alternative method of reasoning that is independent of, but equally useful to, analytical rules.

Decision making. Experts clearly do not use classic formal decision theory, but rather make use of heuristics, or shortcuts, when making decisions. Nonetheless, experts generally make appropriate decisions. This suggests that the shortcuts are useful more often than not. Rather than teaching learners to avoid heuristics, then, it might be more reasonable to help them recognize those relatively infrequent situations where their heuristics are likely to fail.


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Teachers of education and teachers of psychology are uncomfortable bedfellows, frequently approaching issues of learning from very different perspectives and with different goals. They are usually housed in different buildings on the campus, they are often in different faculties, they attend different conferences, and they publish in different journals. Yet there is, or should be, considerable common ground, since both have major interests in learning and memory.

One possible reason for the lack of overlap is that, until fairly recently, psychology was dominated by the behaviorist tradition, begun by Watson, Thorndike, and James at the turn of the century. The basic tenet of behaviorism is that all aspects of human behavior can be understood by a careful examination of the relationship between input (the stimulus) and output (the con-
ditioned response), without reverting to mentalistic concepts such as imagery, thinking, or reasoning. The tradition was philosophically grounded in a positivist view of science, which gave priority to objective, countable units of behavior and which eschewed the soft and subjective information available from introspection. As Watson said:

Behaviorism claims that consciousness is neither a definite nor a usable concept. The Behaviorist, who has been trained always as an experimentalist, holds, further, that belief in the existence of consciousness goes back to the ancient days of superstition and folklore.1

To contemporary educators in the professions, accustomed to thinking about problem solving, reasoning, critical thinking, and self-assessment, such ad hominem judgments may seem the antithesis of the values and goals of liberal education, and as a result, behavioral psychology may seem to have little to offer education. In thinking thus, we fail to recognize the extent to which this philosophy has permeated the culture of professional education. We are still admonished to write our course objectives in behavioral terms, bearing direct allegiance to the primacy of observable, countable, discrete behavior. Performance evaluations, such as the objective structured clinical examination and the patient management problems before it, are explicitly scored using the underlying assumption that all that is of value in clinical competence can be measured in small, discrete, observable, behaviors—this despite evidence that subjective global impressions of examiners are as reliable as and more generalizable than neatly objectified checklists.2

In the 1960s, experimental psychology underwent a quiet revolution. Behavioral psychology with its rats and pigeons was gradually superseded by a renewed interest in human thinking in the context of realistic tasks. A number of forces contributed to the emergence of the new field of cognitive psychology: the work in artificial intelligence of Newell and Simon,3 the recognition of the activities of British psychologists such as Broadbent who had never abandoned the study of human thinking, and the work in linguistics in the 1960s. But many mark the turning point of the revolution by the publication of a textbook, Cognitive Psychology, by Neisser4 in 1967. Today, there are many journals catering to aspects of cognitive psychology. Moreover, many of the prestigious journals in the field, which were formerly dominated by studies in behavioral psychology, are now almost entirely devoted to cognitive research. As a footnote, given the aversion of the behaviorists to introspective methods, it is ironic that simple introspection is rarely used as an experimental device by cognitive psychologists and that the measures employed in their research, such as response times or error rates, are as scientifically credible as any used by the behaviorists.

What is cognitive psychology, and what distinguishes it from other specialties of psychology? Simply put, the object of study is how humans think. While such a statement legitimizes the study of mental processes, in fact, the study of thinking leads rapidly to a study of human memory, since memory has emerged as a central feature of human thought and expertise. As Simon put it: “The essence of intelligence is less a matter of reasoning, and more a matter of knowing a lot about the world.”5 The study of memory is a dominant, though not exclusive, theme in cognitive research. Learning, the central focus of educators, is also of primary interest to psychologists, since it is the process whereby sensory experience is placed in memory.

THE INFORMATION-PROCESSING MODEL

As Jonathan Miller6 has pointed out, many advances in science must await the availability of suitable analogies. Harvey was able to advance his theory of cardiovascular circulation, with the heart as a pump, in part because suitable mechanical pumps had been invented by contemporaries. Similarly, advances in cognitive psychology were spurred on, in part, by the availability of electronic computers as a metaphor of the mind, which led to the model of thinking as information processing. The analogy was exploited in two ways. First, the analogy led to efforts aimed at formal simulation of mental processes on a computer, using the methods of artificial intelligence. These efforts have accelerated concurrently with the increasing availability and sophistication of computer hardware, and have made some inroads into medical education. Because we intend to restrict our perspective to the findings of cognitive psychology, the many developments arising from research in artificial intelligence are not discussed further. However, for the sake of definition, we briefly allude to some of these research domains, and, where possible, identify key references.

1. Expert systems. Generally, expert systems are an attempt to build a program on the computer that incorporates all the complex internalized rules of the expert. The starting point is the expert, and considerable time is required for interrogation of experts and representation of their analytical knowledge in the computer.2

2. Lens model and behavioral decision theory. This approach eschews any direct interest in the proclaimed rules of the expert. Instead, expert judgment is used only to make decisions (frequently probabilistic ones about the outcomes of particular judgment tasks, for example, weather forecasting, disease likelihood, or quality of livestock). Regression approaches are then used to weight the various input cues to best predict the judges’ decisions. General findings from this literature are that such linear models do remarkably well

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at “capturing the policy” of the judge, that the models are highly robust to the effects of modifying the weights of the cues (leading to some divergence about the meaning of policy capturing), and that judges are rarely aware of their own policies.

3. Neural networks. While originating in cognitive psychology as a model of memory (called parallel distributed processing), neural networks have now been used in many applications from medicine to chemical engineering. In direct contrast to the two previous approaches, the neural network learns nothing from experts. Rather, the network “learns” directly from cases with known outcomes. In the internal workings of the network are a series of interconnected layers and nodes, and learning consists of incrementing the weights of particular paths connecting nodes. While this may well be a reasonable model of the working of human memory at the molecular or neuronal level, it is of limited utility to assist human learning, because the internal paths are inaccessible, and, even if accessible, would not be teachable.

Of more relevance to the present paper, the computer metaphor has been used for the purposes of theoretical modeling of the mind as an information-processing system. This involved efforts to reveal the nature of the system’s various components, such as the limits of capacity of short-term memory. Because the structure of the information-processing model remains a valuable framework for subsequent elaboration, we describe it in more detail.

The model was conceived as containing several separate stages through which information from the environment passed. Thus, there was perceptual memory, analogous to the input/output devices of the computer; short-term memory, analogous to the computer’s random-access memory; and long-term memory, analogous to the computer’s permanent storage devices (hard drives or disks). Each of these memory stages was thought to have its own set of properties and limitations. For example, perceptual memory was thought to be quite large but very short-lived (a second or two at most), and information was thought to be stored in the same form as the original stimulus (a visual afterimage or an auditory echo). Short-term memory was thought to last somewhat longer (although still less than half a minute unless the information is refreshed by repeating it) but was very limited in size (Miller’s famous 7 ± 2 chunks). Information in short-term memory was thought to be stored as an auditory signal. Thus, you don’t remember the image of the numbers from a telephone book; instead you keep them in short-term memory by “saying them to yourself” repeatedly. Finally, long-term memory was thought to be essentially unlimited in time and capacity, with information being stored “semantically” (on the basis of meaning), but with relatively slow and effortful storage and retrieval.

When researchers began to look more closely at the various stages, the evidence for separate memory systems began to crumble. What were thought to be specific properties of each stage seemed to be present in all the stages. For example, meaning was shown to be an important component at all stages. And the impact of meaning affected researchers’ conclusions about the capacity and time span of each stage. Now it is more common to distinguish between different uses of the same basic mechanism.

However, it is still useful to draw a distinction between memory when used for storage and memory when used for the active manipulation of information. Thus has developed the notion of working or active memory as distinct from stored or long-term memory. This working memory is more than just a temporary storage place for information that is on its way to long-term memory. In fact, it is not thought of as a “place” at all. Instead, it is considered the process of engaging the higher cognitive functions, the act of thinking. Working memory is limited, not because it is a small box, but because the act of thinking requires active effort and attention, and these resources are limited (we can only concentrate on so many things at once).

A similar evolution has been experienced in our understanding of long-term memory. For example, long-term memory has been subdivided into an episodic memory system (what you had for breakfast this morning) and a semantic memory system (the rules for long multiplication), or subdivided into a procedural knowledge base (riding a bicycle) and a declarative knowledge base (the features of pericarditis). But, again, subsequent investigations have blurred the boundaries of these subsystems. For example, if you are asked to describe the characteristic features of a station wagon, you may have available a list of propositions or features containing the distinguishing features (semantic knowledge), or you may recall your uncle’s Buick Country Estate and then describe the features as you scan the mental image (episodic knowledge). Either approach suffices to complete the task, and the mode of processing cannot be distinguished by the output. Alternatively, it is tempting to use the procedural/declarative distinction to separate individuals who “really know” a topic from those who just possess a set of inert facts (just declarative knowledge), or to separate those who “really know” from those who are just imitating an action without any real understanding (just procedural knowledge). However, this effort is filled with dangers and pitfalls. Both procedural and declarative knowledge are composed of important and useful memories. What distinguishes them seems not to be where they are stored but how they are used (diagnosing versus teaching or test-taking or searching a book). Similarly, it is difficult to maintain the distinction for many concepts such as “gravity,” “covalent bonding,” or, for that matter,
"long-term memory." As Bereiter has pointed out, to effectively use these concepts in solving problems requires far more than the ability to define the term verbally (declarative knowledge), yet concepts are difficult to view as procedures.

Thus, although cognitive psychology began with a computer metaphor, much of the more recent work in the field has pointed out the inadequacies of the model and thereby revealed many of the special characteristics of human information-processing that make it different from computer processing. It is in this area that we can gain valuable insights for education. The topics we consider are:

1. The organization of long-term memory
2. Influences on storage and retrieval from memory
3. Problem solving and transfer
4. Concept formation, prototypes and instances, and pattern recognition
5. Decision making

With each topic, we begin with a summary of current findings in the field and then explore the implications for teaching and learning.

**The Organization of Memory**

**Current Findings**

Within research on medical reasoning, there has been a significant shift away from an attempt to characterize general problem-solving strategies of expert clinicians toward an emphasis on expert memory, particularly the structure and organization of memory. Several contemporary researchers have borrowed theory and methods from psychology to characterize the organization of memory. Thus, Bordage and Lemieux view memory as a set of "semantic axes," while Patel and co-workers model expert reasoning by elaborate propositional networks. Implicit in these views is the idea that the relations depicted in the model have an equivalent representation in memory.

What, then, is known about the organization of memory? One way of expressing the relationship between memories is the notion of a semantic network. The semantic network is an elaborate set of connections between abstract concepts and/or specific experiences. These linkages between concepts and experiences are based on meaning. Some linkages are quite strong and others are weaker, depending on the degree to which the individual associates the two pieces of information in memory. Further, some pieces of information are linked directly, whereas others may be connected only by way of a third concept. For example, in a semantic network of pulmonary physiology concepts, the concept of diffusion might be directly associated (linked) to the concept of lung perfusion, or the two concepts might be linked only indirectly through their common linkage with the more central concept of gas exchange.

The existence of semantic networks has been identified in various ways. One of the simplest methods of identifying semantically related concepts is free association. For example, people given the word "hot" are likely to retrieve the word "cold," suggesting that the two are semantically related in memory. A second, similar method for establishing and assessing the nature of semantic networks is the priming procedure. This procedure involves the presentation of two words in rapid succession and a measurement of the time required to identify the second word. If the two words are semantically related (e.g., bread/butter), the second word is identified more rapidly than if the words are semantically unrelated (nurse/butter). A third method for establishing the nature of an individual's semantic network involves asking the individual to rate the relatedness of a large number of concepts presented as pairs. Assuming that each pairwise rating reflects the strength of the semantic association between the two concepts, it is possible to construct a representation of the individual's semantic-memory network.

It is argued that the acquisition of expertise in an area is characterized by the development of elaborate semantic networks. Initially, a novice has only a few, loosely related concepts. With experience, new concepts and concrete examples are added to the network and new, stronger, richer connections are made between existing concepts and examples. Thus, "true understanding" of a domain is defined not simply by the quantity of information that a person possesses, but by the extent to which this information is organized into a coherent, mutually supportive network of concepts and examples. This is not to say, however, that experts' networks are more "correct" than those of novices. Evidence in cognitive psychology and medical education suggests that the networks of experts even within the same field only remotely resemble each other. Grant and Marsden, for example, showed a "massive variability" among experts in the way information is organized. They concluded that "not even a similar amount of clinical experience confers similar thoughts." McGaghie and colleagues, despite efforts to demonstrate strong agreement by expert groups about the latent structure of pulmonary physiology concepts, were forced to conclude that consensus about the network structure of pulmonary physiology concepts is difficult to achieve even within an expert group. There is even question in the cognitive psychology literature about the consistency of such structures measured within the same individual in different contexts. Thus, the same set of concepts may generate a very different pattern of interrelationships if the individual is considering them in the context of diagnosis versus pathophysiology versus management.

Despite their apparent idiosyncrasy,
these organized, elaborated memory structures enable experts to operate effectively within their specific domains. Information from a case "activates" information or concepts or examples within the cognitive network, which in turn activate yet other relevant information or concepts, and so on. Thus, very rapidly, the full weight of the elaborate, organized memory structure can be brought to bear on the new case. Relevant information is immediately available and the implications of that information rapidly follow. This provides the expert with certain assumptions and hypotheses that, in turn, guide further inquiry until a solution is confirmed. In this sense, the act of diagnosis for an expert is not a matter of applying an abstract, general, hypotheticoductive problem-solving strategy to some specific content. Rather, each case to be diagnosed is likely to lead to an idiosyncratic activation of an individual's idiosyncratic semantic network.

Implications for Education

If this conceptualization of expertise is legitimate, several implications for teaching follow. First, it should be obvious that information in isolation is inert and unhelpful. Only when the information is integrated into the individual's semantic network will it be available and functional for future purposes. In addition, if this conceptualization is legitimate, then it is inappropriate to try to teach clinical-reasoning skills independently of clinical context. The two are inextricably intertwined for the expert and must be integrated during the development of expertise. These issues are further elaborated in the sections to follow.

Influences on Storage and Retrieval from Memory

Current Findings

Psychologists have extensively investigated factors that influence the ability of humans to store and retrieve information. A central theme is the idea that forgetting is strongly related to an inability to access or retrieve information, rather than a decay in the information trace in memory. That is, for human memory, forgetting is a failure of retrieval; knowledge may be present in memory, but it is not accessible. One line of evidence for this claim is the dissociation between recognition and recall. As educators, we frequently display an aversion to multiple-choice tests because "multiple-choice questions (MCQs) just test recognition, not the ability to recall knowledge," an implicit acknowledgment that the information is in memory (in order to permit accurate recognition), but cannot be recalled directly. There are experimental demonstrations of the phenomenon; for example, Mandler and colleagues conducted a memory experiment in which they examined the difference between recall and recognition by presenting subjects with lists of 100 words that the subjects were asked to memorize. Then the subjects were asked (1) to directly retrieve the words from memory, without any prompts, and (2) when presented with additional lists that contained both old (i.e., previously learned) and new words, to distinguish the old words from the new ones. Average recall (recognizing the words without prompts) was 38%, whereas recognition (distinguishing the old from the new words in the lists) was 96%. So the information about the old words was present in memory, aiding recognition, but could not be directly retrieved.

However, things are not quite as simple as all that, and demonstrations of an inverse relation between recognition and recall are not uncommon. As one example, common, high-frequency words such as "read" and "horse" are more easily recalled, but less easily recognized, than less common words such as "reed" and "hoarse." It is also possible to reverse the accuracy of recognition and recall by manipulating the test conditions.31 As an aside, while the two processes are demonstrably different, in standard testing situations they appear sufficiently highly correlated that the choice of test format (MCQ or free response) need not be dictated by a concern for the dissociation between recognition and recall.32

In contrast to computers, human memory is strongly influenced by a number of factors. Perhaps the strongest influence emerges from the degree of meaning we can impose on the stimulus. A second feature is context specificity, the degree of match between all the situational features at the time of learning and the time of test. A third well-described factor is processing specificity, the idea that how you learn something will have an important effect on how you are able to retrieve it. And a fourth factor is practice on the task of remembering.

The effect of meaning. Although as educators we tend to think of memorization as rote, with the implication that it is a meaningless and mindless activity, many memorizing activities are far from devoid of meaning. Consider the following lists of words: (1) go placidly amidst the noise and haste, and (2) haste noise placidly amidst the and. It would be easy to demonstrate that the first set of words, whose organization results in a meaningful sentence, is far easier to remember and recall than the second set of words. In the second, by transposing words, we have destroyed meaning.

But it is important to note that meaning, as used in this context, is not a property of the materials alone. Rather it is a characteristic of the interaction between the material and the learner. Both sets of words above would be meaningless to someone who did not speak English. As another example, contrast the following two paragraphs taken from the same page of a research article in a clinical journal:33

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Several groups have identified monosomy 3 and multiplication of the chromosome 8q as non-random cytogenetic aberrations that are specific features of uveal melanoma. These findings have been confirmed by an investigation of restriction-fragment length polymorphisms of the DNA, and by the molecular cytogenetic method of comparative genomic hybridisation.

versus

We assessed the influence of prognostic factors on relapse-free time and overall survival. We used Kaplan-Meier estimates and the log-rank test for univariate analysis. Univariate correlations were done by the Spearman rank correlation coefficient. Because of an association between monosomy 3 and other known prognostic factors, Cox proportional-hazard regression analysis was used to calculate independent relative risks of relapse, after adjustment for covariates.

While the first statement is self-evident to any oncologist, to most lay individuals (and most statisticians) the precise meaning is unclear. Conversely, the second statement is routine for a statistician, but probably holds little meaning for most clinicians.

Becoming an expert in an area in large part involves understanding the meaning of specialized knowledge. Consequently, when shown materials that have specialized meaning, the expert is able to recall more than the novice. This was first demonstrated in chess but has been replicated in many other domains, including medicine. A study by Norman and colleagues involved showing subjects a series of patient “cases,” each consisting of a brief clinical description followed by 20 laboratory values (for serum chemistry, urine chemistry, blood gases, etc.). The average numbers of values correctly recalled ranged from six for novices to 14 for experts. How does the expert achieve this? One hypothesis is that experts simply have better memories than novices. Acquiring expertise is a matter of learning strategies that will help one to remember things better. While such general strategies have been used for millennia to aid memory, a simple demonstration showed that, in the case of experts, this was not the mechanism. When the initial stimuli was replaced by a random configuration (for chess, the pieces were placed at random on the board; for nephrology, the lab data were replaced by random numbers), the advantage of the experts disappeared, with both novices and experts recalling an average of four values. Chase and Simon demonstrated that the experts achieved success by “chunking” the information into meaningful configurations, thereby reducing the memory load. Again, in nephrology, when experts were shown legitimate data in random sequence, they actively sought out related values, such as those for serum electrolytes, in order to reestablish meaning. And when they were given protocols where the individual data were placed in random order on a page, experts, but not novices, actively sought out the data in meaningful units (such as those for blood gases), and when they were asked to recall the data, did so in meaningful clusters.

In the initial learning situation, it is much more difficult to impose meaning on the material, since the concepts are new and the act of learning is, in itself, one of trying to understand new ideas, of finding meaning in the new concepts.

Encoding specificity. When a computer saves and retrieves information in memory, it does so carefully but with little effort at organization. The computer does not care where the various pieces of information are stored. So long as it has its map of locations, the complete set of information is flawlessly retrieved. Even more impressive, if the computer user wishes to know which file contains a specific piece of information (a word or phrase), the computer can systematically check all files and locate and retrieve the piece of information without problem. By contrast, humans are notoriously bad at retrieving information in such a generic, context-free, manner, although when given the right cues (such as a song melody) humans can retrieve information (the song lyrics) with a speed and efficiency that would be the envy of any computer. Therein lies a major difference; for humans, the probability and efficiency of retrieving an item from memory depend on the similarity between the conditions of encoding and the conditions of retrieval. This phenomenon, referred to as the encoding specificity principle, takes several forms.

One manifestation of the encoding specificity principle is the phenomenon of context specificity. No doubt you have had the experience of walking out of the office to perform some task and realizing halfway down the hall that you have no idea what you were going to do. Ironically, when you finally give up trying to remember and return to your office, suddenly you remember. The context of the office becomes a powerful influence on memory retrieval. The phenomenon of context specificity is well established in the cognitive literature. In one classic study with Royal Navy divers, word lists learned on land were recalled better on land and those learned underwater were recalled better underwater. Similar, although somewhat smaller, effects have been observed with college students by changing the rooms in which learning and testing take place. The similarity of the context, however, is not just limited to the external environment. One of the most impressive demonstrations of the range of context similarity was an experiment on “state-dependent learning” in which the state was induced by ordinary or marijuana cigarettes. Again a crossover effect, similar to the one in the Godden and Baddeley experiment, was observed.

A second manifestation of the encod-
ing specificity principle is the phenomenon of processing specificity. That is, how you store something will have an important influence on how you can retrieve it. Again, the power of this effect can be experienced anecdotally. It is difficult, for example, to recite the alphabet backwards, or to recall the months of the year in alphabetical order. The information is clearly available and retrievable but can be remembered only in a specific way. Research evidence in support of this phenomenon has already been presented here. Earlier we discussed the fact that recall can sometimes be better than recognition, i.e., when subjects were trained for the purposes of recall and therefore were less able to recognize. In a similar line of work, Jacoby and Dallas had subjects read some words in isolation and generate other words using a specific formula (e.g., “The opposite of hot is . . .”). They found that the words that were generated were later remembered more accurately. However, the words that were read in isolation were later recognized as words more rapidly. Again, the utility of a piece of information was dependent on a match between the manner in which it was originally stored and the manner in which it was later to be used.

There is evidence of a naive, perhaps implicit, awareness of this phenomenon, and individuals will alter their behaviors to accommodate it. Carey and Lockhart, for example, led subjects to believe that they were studying a list of words either for a later test of recall or for a later test of recognition. All subjects were then given a recognition test. The subjects who knew that they were to be tested for recognition performed better than those who had mistakenly studied for a recall test. Clinical teachers see evidence of processing specificity frequently on the wards. Often academic clinicians are frustrated with the student who can list reams of information about a given disease but cannot connect that information with what is happening in a specific case. This is reminiscent of the procedural/declarative distinction that we discussed earlier and is taken by the teacher as evidence that the student does not “really understand.” Instead, it might be more appropriate to acknowledge that the student has learned the information in the specific form that was most functional at the time (passing his or her course tests) and must now learn to recode and retrieve the information in a clinically useful form. This provides an explanation for the consistent evidence of the impact of a curriculum’s examination philosophy on what and how students are likely to learn. Transfer from examination to clinical setting is impeded not only because students learn different things but also because they learn them differently.

The effect of practice. Perhaps the least surprising influence on memory is study time. For millennia, students have known (or feared) that the time they spend on study will have a direct reflection in their performances on examinations. In fact, the phenomenon is far more persuasive than just examination performance; Ericsson and Charness have demonstrated that expert mastery in many domains, even those that are usually associated with native talent such as chess, sports, or music, is primarily a matter of the time spent in the activity. Similarly, experimental studies have shown that the amount learned is directly and linearly related to the amount of time spent learning, a phenomenon called the “total time” hypothesis.

These comments should not, however, be interpreted to suggest that practice leads to the development of general remembering strategies. Rather, the effect of practice on memory is highly specific. That is, the more often a particular piece of information is retrieved from long-term memory, the easier it becomes to retrieve that particular piece of information again. It is important to note, however, that there is a distinction between retrieval of a piece of information from long-term memory and rehearsal of a piece of information in working memory. Simply repeating a piece of information over and over does not require repeated retrieval from long-term memory and therefore will not be as effective in easing retrieval at a later date. To effectively practice remembering something, one must repeatedly retrieve the information after not having thought about it for a few minutes.

Implications for Education

It is apparent that educational strategies to enhance memory should be directed at three goals—to enhance meaning, to reduce dependence on context, and to provide repeated practice in retrieving information. New information is meaningful only in the light of prior experience; thus we can enhance meaning to the extent that we can invoke or activate relevant prior knowledge. This strategy has been demonstrated in medical education by Schmidt and his associates. They presented small groups of students with a problem either relevant or irrelevant to a text to be studied subsequently. The groups discussed these problems for a specified period of time and subsequently read the text providing new information. The groups discussing the relevant problem recalled significantly more information from the text. The investigators explain this finding by suggesting that problem discussion stimulates the activation and elaboration of prior knowledge, which, in turn, facilitates the processing, comprehension, and recall of the text. Since the groups discussing the irrelevant problem activated knowledge not relevant to the subsequent text, they did not profit from the instructional manipulation. Support for this explanation was found in an experiment in which subjects were required to discuss either a problem to be explained with knowledge they had acquired several
years before or a neutral problem. When required to recall the knowledge acquired before, the groups who discussed the relevant problem recalled much more from their previously acquired knowledge than did the control groups. This suggests that problem discussion indeed activates prior knowledge, both recent and distant, which is elaborated upon and subsequently used for the comprehension of new information.

There are two strategies to deal with encoding specificity. The first is to deliberately attempt to maximize the positive effect of context by making the learning environment and the application environment as similar as possible. This may provide a rationale (if one is needed) for community-based education, where all instruction takes place in patient care and community settings. Certainly, it may be a point to ponder whether we could do better in fostering a match between learning and clinical environments.

Alternatively, Anderson mounts the counter-argument (in the context of concerns regarding testing facts in isolation from the learning context) that knowledge that is so context-bound is of little enduring value in any case. This suggests an alternative strategy—to attempt to actively elaborate the new knowledge. Elaboration is the process of considering a piece of knowledge in a richer, wider context. It may take the form of discussion (e.g., posing and answering questions) or using the knowledge to understand some new or different problem. By elaborating on the knowledge in this way, one expands the context of its use and the manner in which it is processed. Not surprisingly, therefore, elaboration is likely to lead to increased availability of the knowledge in a wider variety of circumstances.

Finally, to maximize students’ ability to use the information taught to them, it is important for educators to avoid the “vaccination theory” of teaching and learning. The vaccination theory states that once students have been taught and tested on a specific body of information, they are immune against that body of information and do not have to study it ever again. Educators must be aware that repeated booster shots are necessary. Students must be challenged to retrieve and use information repeatedly and in circumstances where they might not have predicted the information to be necessary. Only through repeated testing in this manner will students master the ability to retrieve the information when it is necessary.

PROBLEM SOLVING

Current Findings

Medical schools teach the basic principles or concepts of biomedical science in the preclinical years with the implied hope that these important concepts will be available and used in the solution of patient problems. This is an acknowledgment that one cannot solve problems in a given domain until one knows something about the domain. Obviously, without some biomedical knowledge, even the best problem solver could not identify what is wrong with a patient. Such a person would not know what might go wrong or even know what “right” is supposed to be.

But expert knowledge of an area is more than just an extensive set of facts that are available for a general problem-solving machine. And an expert is not merely a good general problem solver with all the facts necessary to apply these general skills in a given domain. Instead, it would appear that the nature of problem solving changes with the development of expertise. In fact, it has been suggested that much of an expert’s performance has little at all to do with the classic interpretation of problem solving. As Anderson has stated: “One becomes an expert by making routine many aspects of a problem which require creative problem solving by a novice.”

For the expert, the solution to a problem within his or her domain of expertise is often straightforward or obvious. One potential reason for this is that identical or similar problems have been solved with such frequency that the expert simply recognizes the problem and remembers the solution. In this sense, expert knowledge is more than merely a set of facts that act as the building blocks for problem solving. The expert’s knowledge also includes a repertoire of problems that are common in the domain and a repertoire of common solutions to those problems. More often than not, an expert is not solving problems but remembering solutions.

The use of analogy. The underlying process involved in this method of problem solving is one of analogy: the process of recognizing that a principle learned in the context of one problem will be effective in solving a second, conceptually similar problem. The difficult step in making use of this analogical strategy is recognizing the conceptual similarity between problems despite changes in the surface features.

Two decades of research on analogical transfer in novices indicates that transfer to analogous problems is extremely narrow. A number of studies of problem solving have shown that any change in surface features or context of a problem impedes transfer so that the problem solver does not recognize the similarity of the underlying concept, and the analogy is not utilized. In light of the previous discussion of encoding specificity, this is hardly surprising, but the extremely limited transfer that is usually observed is surprising.

Some elaboration may be useful. One of the classic problems used in experiments in this tradition involves focusing X rays on a tumor from multiple directions in order to get a sufficiently high radiation dose to the tumor without damaging surrounding tissue. In a typical experiment, subjects read an
analogy problem in which a general captures a fort by sending small groups of soldiers along a number of roads to attack at the same time. When the subjects were told that this problem was analogous, transfer was successful; however, even when the experimenter explicitly explained the underlying principle and drew diagrams, little or no transfer occurred unless the analogy was explicitly pointed out. Multiple (two to three) analogous reading problems appeared to help transfer, but only if the subjects made specific comparisons among the representations. Even after an hour of such comparisons, however, only about half the subjects were able to solve the new problem.

So how can we resolve the apparent conflict between the hypothesis that experts often make use of analogy, recognizing problems and remembering the appropriate solutions, and the research suggesting that people, as a general rule, do not make effective use of analogies? The key is in recognizing the difference in the way that novices and experts perceive problems. Work by Chi and colleagues shows that when sorting a variety of physics problems into groups, novices tended to make heavy use of the superficial characteristics of the problems (e.g., inclined plane problems versus rotating object problems). By contrast, experts tended to ignore surface characteristics and organize problems based on principles of physics (e.g., conservation of energy problems versus Newton’s second law problems). In short, novices are dependent on the surface structures of problems, whereas experts are able to understand the deep structures. It should not be surprising, therefore, to find that changes in surface structure severely affect a novice’s, but not an expert’s, ability to use appropriate analogies.

A demonstration of this phenomenon was provided by Needham and Begg. They recognized that most of the previous experiments in the use of analogy had subjects learn the examples for meaning (for instance, by being asked to recall the text), but did not ask subjects to solve the problems represented in the examples. The experiments were encouraging subjects to act as novices. Thus, Needham and Begg contrasted two groups of subjects. All subjects worked on a series of five problems. Some were asked to remember the problems (focusing on surface characteristics as a novice might), while others were encouraged to attempt solutions to the problems (focusing on the deep structures of the problems as an expert might). Both groups then received an explanation from the experimenter about the underlying principles. The results showed that subjects who were asked to solve a prototype problem and received feedback about the problem typically transferred the concept to a new problem nearly 90% of the time, versus about 60% for those who were asked to memorize the problem. It is worth noting, however, that although the subjects in the memorize condition solved the new problems less frequently, they did actually remember more of the original problems than did the subjects in the problem-solving condition. Thus, the low transfer rate to new problems for subjects in the memorize condition was not a result of cursory, less effortful processing of the initial problem. Rather, it was probably the expert-like training procedure that allowed the problem-solving group to transfer so effectively.

**Specialized problem-solving routines.** The good general problem solver will often be able to work out a general principle and therefore apply a general problem-solving routine in a reflective and considered manner to a specific situation. When a general routine is used repeatedly within the context of a specific domain, however, the general strategy often evolves into a highly specific strategy (or set of strategies). The use of the routine is adapted to the situation, becoming highly specialized and automated. Once this occurs, the general

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by checking whether a car that won’t start has gas in the tank. The general principle underlying both solutions is the same: ensure that there is an energy supply before testing for more complicated explanations. However, the general rule has become specialized for the expert: check that the television is plugged in. It is important to stress that this example is not intended to highlight the foolishness of the television repair person. Rather, as with Luchins’ subjects, the individual has adapted a general routine to maximize productivity within a specialized domain. While the inability to transfer the general concept from televisions to cars may make the individual a poor car mechanic, it is exactly this specialization that makes the individual an efficient and effective television repair person.

Implications for Education

Together, research on the use of analogy and research on the specialization of problem-solving routines paint the picture of an expert who is effective at solving problems in his or her area of expertise because he or she has had extensive practice solving problems in that area of expertise. This is consistent with a large body of work on expertise that suggests that the distinction between the virtuoso and the merely competent is the amount of practice on the task.9 But, again, we wish to stress that the nature of the practice is vital. The work on the specialization of routines suggests that individuals must practice the same problem-solving routines repeatedly. The work on analogy suggests that, in addition, the novice must have extensive practice in identifying the situations in which a particular problem-solving routine is likely to be useful. While education programs are often effective at fulfilling the first requirement, they are often ineffective at fulfilling the second. Often when students are taught about a concept, the teaching is supplemented by practice in applying the concept to a set of problems arranged so that the problems on which the student is expected to work are all problems to which the concept applies (“Now do questions 1 to 3 at the end of the chapter”). Thus, the student receives experience in explaining how a concept applies to various cases, but receives no experience in trying to recognize whether the concept is appropriate for the problem being addressed. By contrast, when the student is being tested (or is placed in a clinical setting), each problem faced could represent any of a huge array of concepts, and the student is expected to determine which concept is relevant for the case. If we want a student to select the appropriate concept in the clinic, we must give the student practice in selecting the appropriate concept during training.

CONCEPT FORMATION, CATEGORIZATION, AND PATTERN RECOGNITION

Current Findings

Essential to the skill of the clinician is the act of categorization, i.e., deciding, on the basis of signs and symptoms elicited from the patient, the diagnostic category and treatment choice to alleviate or cure the problem. The question of psychological interest is how the clinician makes this categorization judgment. Research in clinical reasoning, focusing on the diagnostic task, is now over two decades old and has been approached using a variety of strategies from statistical to semiotic. The majority view is that clinical reasoning is a deliberative act, which involves the eliciting of features of the patient that are then incorporated into a diagnostic rule (of the form “if the patient has chest pain, and it is crushing in character, and radiates down the left arm, then it is probably a heart attack”). While this is a likely mode of reasoning in some circumstances, research in cognition suggests some alternative means to achieve the same end.

For the present discussion, we must recognize that the act of diagnosis may be analogous to many decisions made in everyday life, such as deciding that the individual approaching you is yourdaughter, the four-legged beast on the other side of the street is a dog, or the sporty car approaching at high speed is a 1957 Corvette (while these are categorizations involving visual stimuli, so are those involved in dermatology, radiology, pathology, and, to large degree, general practice). One way to describe a possible mechanism is quite analogous to the clinical example of heart attack that we gave earlier—if it has floppy ears, and it barks, and it wags its tail, then it is probably a dog. At issue is whether this is the only, or even the most effective, way to approach such tasks.

For the past 30 years, some psychologists have been particularly interested in how people learn to do these categorizations. Early views of the process of concept formation were more philosophical than psychological, searching for logical combinations of features that would define categories (for example, “bird”—can fly, has wings, two feet, lays eggs). Unfortunately, ostriches and penguins do not fly, bats have wings, alligators lay eggs, and humans have two feet. It became evident that natural categories cannot be easily described by logical relations. Instead, they are constructed from “family resemblances,” such that members of the category share features, but no feature or combination of features is vital for category membership. Some members will possess a large number of these shared features and therefore are more prototypical of the category (e.g., a robin is prototypical of the category “bird”). Other members will have far fewer of the features and therefore are less typical (e.g., penguins and ostriches). Extensive research on prototype theory has shown that prototypical family
members are mentioned more often by subjects in a free-recall task, are rated as more typical of the category, and are identified as being more typical than atypical members. Some research in medicine has shown similar findings for medical categories; for example, diabetes is a prototypical example of endocrine disorders and has all the properties listed above. The view of prototype theory is that individual examples are somehow abstracted into a prototype or a series of prototypes. The individuating characteristics of each individual case, then, are lost in the general abstraction. When a new instance of a class is encountered, a systematic search of the features of the new instance against the features of class prototypes yields a decision about the likely class to which the new stimulus belongs and the typicality of the instance as a representative of that class.

Within medicine, much of the teaching we perform is an implicit acknowledgment of this prototype model of classification. We often begin the teaching process by providing a verbal prototype (a feature list of the typical diagnostic indicators) of the category. Further, we often teach by providing prototypical examples (the classic case), thereby providing a good representation of the "average" without necessarily giving a proper representation of the variability around that average. Yet in the psychology literature, there is some debate about the nature and utility of these prototypes. In favor of the prototype model, it is clear that individuals can describe the general, prototypical case. Further, there is little doubt that individuals can make reference to a set of abstract, prototypical features when asked to justify a diagnosis. However, experiments by Barsalou raise questions as to whether these structures exist prior to asking about them. Barsalou had subjects develop new categories on the spur of the moment (e.g., "good places to hide if the Mafia were trying to kill you" or "things you would take out of your house if it was burning"). Such categories were unlikely to have existed for subjects prior to exposure in the experiment. Nonetheless, these "ad hoc" categories created by subjects on the spur of the moment demonstrated all the qualities of a prototype category. Further, Kahneman and Miller have shown that the prototypes themselves will vary depending on the contexts in which they are evoked. These studies lead to the conclusion that prototypes may not be the permanent, stable entities in memory that were originally proposed. Rather, they may be generated "on the fly" from available cases whenever they are needed.

Research has also led to questions about whether prototypes are used for the purposes of diagnosis on a regular basis. They may be useful for some kinds of diagnostic tasks, such as the relatively systematic search of history and physical to confirm or refute hypotheses. But they may be far less useful for the early hypothesis-generation phase of diagnosis, which occurs very rapidly, with minimal information, and frequently with minimal effort. Indeed, we often advance hypotheses about likely class without any conscious awareness of processing feature by feature. We are able to recognize dogs and cats almost instantly, long before they bark or wag their tails: It's a dog because it looks like a dog... period. Experienced clinicians find themselves in a similar situation—"this patient likely has asthma. Why? Well, because patients who are like this usually have asthma."

To account for these observations, some psychologists have pursued the idea that categorizations may occur by means of a very different mechanism. The individual instances that make up prior experience are not abstracted into a set of prototypes; instead they are individually and nearly instantly available, given the right set of retrieval cues. Thus, when we say it's a dog because it looks like a dog, what we are really saying is that it's a dog because it looks like Margie, who was Aunt Sally's golden retriever. One simple demonstration of the phenomenon is to ask a middle-aged car buff to recall, for example, a 1958 Chevrolet. Once done, you then ask the color of the car, which is usually forthcoming. Now, 1958 Chevys should be eminently amenable to prototype formation since there is relatively little variation about the prototypical 1958 Chevy. And if the prototype had a color, it would be a muddy gray brown, since that is what happens when you mix all the colors together. But that is not the response—typically, it's red or white or metallic blue or whatever. And on further inquiry, it belonged to the kid down the street, or your brother George, or whoever. In short, when asked to retrieve the category "1958 Chevy," people almost routinely retrieve a particular instance of the category.

A number of experimental studies using artificial materials have demonstrated the memorability and utility of prior instances. It is also important to note that many of these studies have demonstrated an effect of similarity to prior instances without subjects' awareness of the effect. Under these circumstances, it is likely that people will underestimate the extent of similarity and ascribe their efforts to automaticity, intuition, or unconscious problem solving, or to rapid application of the appropriate rules.

A similar study was conducted of medical students and graduate students using a similar learn-test strategy. This study showed that the effect of a similar-appearing example from the same or an alternative diagnostic category during the learning phase was sufficient to change the percentage of correct diagnoses from 42% to 89%, over intervening time periods as long as two weeks.

A recent study attempted to explore the relative contributions of non-analytical case-based and analytical feature-based processing on diagnostic reasoning in dermatology and their
relationships to processing instructions. Sets of slides were carefully constructed to reflect typical/typical and similar/dissimilar relationships. Residents were trained on one slide from each set and tested on other slides, with directions to select a diagnostic label based on either (1) first impression or (2) arguing for alternatives. The results demonstrated a consistent advantage for similar slides, amounting to about 40% in accuracy, regardless of instructions. Under the alternative condition, typical slides were diagnosed about 15% more accurately than atypical slides, resulting from a slight increase in accuracy on typical slides and a slight decrease in accuracy on atypical slides relative to the first-impression condition. The results are a clear demonstration of the central role of similarity to previous cases in dermatologic diagnosis.

While these studies were designed to demonstrate the influence of prior processing episodes on diagnosis, there is no intention to claim that prototypes do not exist. At one level, clearly they do: medical textbooks are compendia of disease prototypes. Moreover, the systematic search for data in the deductive phase of hypothetico-deductive reasoning is likely to be highly analytical, and may well involve systematic matching of features against disease prototypes. Instead, the claim is that both modes of inquiry are available and they are used in different circumstances.

Implications for Education

Whether instance effects can be demonstrated in other domains of medicine remains to be shown. Regardless, the evidence in dermatology indicates that the phenomenon does exist. It also provides a psychological basis for our intuition as consumers of professional service, namely, that experience after graduation and licensure is of crucial importance to expertise, and it forces us as educators to more critically examine the relative contributions of analytical "textbook" knowledge and experiential knowledge to professional expertise. These studies demonstrate that experience with example cases is not just an opportunity to apply and practice the rules "at the end of the chapter." Instead, experience with cases provides an alternative method of reasoning that is independent of, but as useful as, analytical rules.

The challenge remains to explore whether we can develop a pedagogy of experience (for example, strategies to structure experiences in order to maximize the effectiveness of non-analytical reasoning), or whether such experience is simply a case of acquiring many examples in practical settings in order to achieve competence.

**DECISION MAKING**

**Current Findings**

There is an extensive literature concerned with how physicians make decisions, or perhaps more accurately, how they should make decisions. One theme of this literature is concerned with the identification of the biases present in human decision making. One example of findings in this tradition is the "vividness" bias, where vivid examples have a greater effect on our decision making than more common, less vivid examples. In medicine, this may result in using, or avoiding, a therapeutic approach because of one patient for whom it worked surprisingly well or went spectacularly wrong. Since the introduction of these potential biases in decision making into the literature, many have been documented. The recurrent theme of this approach is that humans are prone to biases to the detriment of decision making, and they should either (1) be taught about these biases, so they can learn to avoid them, or (2) be supplemented by mechanical decision-making algorithms that are not so vulnerable.

On the other hand, in relatively heterogeneous domains, physicians have been shown to consistently perform at least as well as computer diagnostic systems. As Swanson and colleagues state:

"[Computers'] diagnostic performance is approximately at the level of the human expert. Unfortunately, performance expectations have been higher than that, given the obvious advantages of the computer in memory reliability and computational speed. It is less surprising that machines perform as well as experts, than that experts perform as well as machines. Experts must have a better representation of disease, better inferential methods, or both, given that they are at an architectural disadvantage."

It is worth noting that the term often associated with biases is heuristics, where a heuristic could be defined as a strategy to rapidly achieve a goal most of the time. From this perspective, heuristics may be seen as the relatively efficient and adaptive mechanism used by experts to deal with the capacities and limitations of human cognition. The simple fact is that good physicians are usually correct and efficient. Perhaps this is because of the biases and heuristics rather than in spite of them.

**Implications for Education**

One implication from the literature on heuristics and biases is that medical students should be taught about biases, admonished to be aware of their pervasive nature, and trained to avoid them. We are not aware of any evidence that such error-correcting training can be successful. In fact, the literature on the context-dependence of problem solving reviewed here strongly suggests that such general strategies toward caution are unlikely to be successful. Perhaps rather than focusing on "debiasing," instruction should be directed at helping students to recognize those relatively infre-
quent situations where their heuristics are likely to fail.

A second implication is that medical students should be taught to make extensive use of decision-support systems, which are designed to be immune to decision biases. Again, however, one might question the advantage of such an approach. The promotion of these tools is based on the information-processing model of human thinking. It assumes that the data that are necessary to generate the appropriate conclusion are available to the student independently of the answer itself. The student need only input all the data and let the support system generate the answer. Unfortunately, research indicates that the collection of data is strongly influenced by the hypothesis being entertained. Without a hypothesis, even experts often fail to see the data that the decision-support system would require to generate the correct response. Thus, the utility of the decision-support system will be severely limited by the decision-making ability of the user. To the extent that the user is biased, the support system is likely to be as well. Again, instruction might be better aimed at helping individuals decide when the decision-support system could be beneficial rather than at teaching individuals to rely on it extensively.

**Conclusions**

This paper has reviewed current concepts in cognitive psychology related to the nature of human learning, with a view to examining their influence on teaching in the professions. From this perspective, several general conclusions may be drawn. First, our ability to perform thinking tasks is importantly related to our success in retrieving relevant knowledge from memory. In turn, there are a number of factors that influence the success or failure of this mental operation, related, in a general way, to the degree of match between the conditions under which the knowledge was initially acquired and the conditions of retrieval. Second, practice is vital to the development of expertise. However, this practice should not be directed at the development of general, overarching skills such as memory enhancement, generic problem solving, or logical decision making. Rather, practice should be directed at developing a large repertoire of highly specific skills. Further, teachers and learners must always maintain a clear recognition of the ultimate goal and ensure that the tasks being practiced are consistent with that goal.

We began with the perspective that education and psychology have pursued parallel paths for too long. It is a significant consequence of this phenomenon that many of the implications for education that we have deduced from the psychological literature must be considered to be hypotheses, with no direct evidence of effectiveness. It is clear that the merging of these two disciplines will result in fruitful lines of inquiry for both educational researchers and cognitive psychologists.

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