Educational Psychologist
1979, Vol. 14, 15—23

Information-Processing Analysis of College Teaching

Robert A. Bjork
University of California, Los Angeles

This article constitutes an optimistic argument that basic research on human cognitive processes has yielded principles and phenomena that have considerable promise in guiding the design and execution of college instruction. To illustrate that point, four somewhat interrelated principles and phenomena are outlined and some possible implications and applications of those principles and phenomena are put forward.

There is, among many psychologists and educators, a remarkable pessimism with respect to the transformation of basic research on learning and memory to college teachning. I do not share that pessimism. In particular, I think that recent research on human information processing has been quite rich in principles and phenomena that have potential applications to college teaching. In what follows, an outline of several specific principles and phenomena that I believe are especially promising in their possible application is presented first. I then illustrate their possible implications for three important aspects of college instruction: (a) how to study, (b) course design, and (c) the lecture.

Selected Principles and Phenomena

The four principles outlined below were selected on the basis of my judgment that these principles and phenomena are among the most reliable and incontrovertible to be gleaned from recent research on human information processing.

The Spacing Effect

One of the most reliable phenomena in human experimental psychology has come to be termed the spacing effect. The spacing effect can be schematized as shown below, where P_1 denotes a first presentation of some verbal information, P_2 denotes a second presentation of the same verbal information, and "Test" denotes an experimenter-induced or subject-induced attempt to recall the information presented at P_1 and P_2.

$$P_1\ P_2 \cdots\cdots\cdots \text{Test}$$
$$P_1 \cdots\cdots P_2 \cdots\cdots\cdots \text{Test}$$

The top condition illustrates massed presentations where there is little or no temporal separation of P_1 and P_2; the bottom condition illustrates spaced presentations where there is a substantial temporal separation of P_1 and P_2. The dotted lines separating events in the illustration above are meant to symbolize that, typically, the intervals from P_1 to P_2 and P_2 to "Test" are filled with some kind of ongoing activity (such as attempts to memorize or recall other verbal items).

The "spacing effect" refers to the fact that spaced presentations yield substantially better long-term recall than do massed presentations. The size of the effect is often striking: In some situations, the level of recall following spaced presentations is more than twice the level of recall following massed presentations. In addition, the spacing effect holds for a great range of time intervals and types of to-be-remembered information. It has been demonstrated repeatedly in the free recall of individual words and sets of several words (e.g., Melton, 1970), in the cued recall of individual paired associates (e.g., Peterson, Hillner & Saltzman, 1962), and in the recall of meaningful materials such as sentences (e.g., Rothkopf & Coke, 1963; D'Agostino & DeRemer, 1973). There even appear to be

This article was accepted by the former editor, Margaret M. Clifford.

This article is a revised version of a paper presented in a Symposium on the Transformation of Research on Learning to College Teaching at the annual meeting of the American Psychological Association, San Francisco, September, 1977. It was completed while the author was a Visiting Consultant in the Human Information-Processing Research Department, Bell Laboratories, Murray Hill, New Jersey.

The address of Robert A. Bjork is Department of Psychology, University of California, Los Angeles, California 90024.

spacing effects in the long-term acquisition of telephone numbers (Landauer & Ross, 1977). In fact, about the only exceptions to the spacing effect that are worth mentioning are the following: (a) At very short P_2 - Test retention intervals (less than 20-30 seconds), spaced presentations sometimes yield worse performance than do massed presentations, and (b) the spacing effect is largely a recall phenomenon; when long-term recognition rather than long-term recall is tested, the spacing effect is greatly reduced.

It is worth nothing that the spacing effect is quite surprising from an intuitive standpoint. One might reason, for example, that since the retention interval from P_2 to Test is the same in both cases, and since the retention interval from P_1 to Test is shorter in the massed case, performance should be better in the massed condition. A number of experimental psychologists (including myself) have spent considerable time and effort formulating and advocating various theories in an attempt to account for the details of spacing phenomena (for particularly promising approaches, see Glenberg, 1976, and Landauer, 1975). The jury is still out, however, and for present purposes we need not consider the various theories that have been advanced. From a practical standpoint, it is enough to know that the spacing effect is both sizeable and reliable; it has important implications whatever the mechanism involved.

Variable Encoding

In its various forms, the notion of encoding variability has been quite influential during the last decade in basic research on human learning and memory (e.g., Martin, 1968, and Bower, 1972). At a simple level, the idea can be characterized as follows. Whenever humans attend to verbal information, they encode that information in some way. It is the information as encoded (the functional stimulus) rather than the information as presented in its nominal, physical form (the nominal stimulus) that governs later recall and recognition performance. Owing to intrinsic and extrinsic sources of variability, the encoding of a particular verbal item may differ for a given individual at different times and in different contexts. Thus, "bank" may be encoded as a building where one keeps money on one occasion and as a slope next to a river on another occasion. With much more complex to-be-learned verbal information as well, there may be differences in the way that information is encoded at different times and in different contexts.

There is now considerable evidence that retrieval of information profits from variability in the encoding of that information. Consider, for example, the results of an experiment by Gartman and Johnson (1972). In this experiment, subjects were asked to study lists of individual words, and after each list they were asked to free-recall as many words as they could from that list. Some of the words in a list were repeated, and Gartman and Johnson arranged the words in the list so that the words presented just prior to each occurrence of a repeated word would induce a particular encoding of that word. In one condition (the same-context condition) the same encoding was induced on both presentations. In the other condition (the different-context condition) two different encodings were induced. Thus in the example below, the words preceding the repeated word "foot" in the same-context condition bias its encoding toward the part-of-a-body sense of "foot" on both of its presentations, whereas in the different-context condition the encoding of "foot" is biased toward its part-of-the-body sense on its first occurrence and toward its unit-of-measurement sense on its second occurence.

SAME CONTEXT:
. . . arm leg foot . . . chin knee foot . . .

DIFFERENT CONTEXT:
. . . arm leg foot . . . inch meter foot . . .

In Gartman and Johnson's experiment repeated words were recalled very much bette in the different-context condition than the were in the same-context condition (in fac the frequency with which same-conte words were recalled was several times as high the frequency with which same-contect wor were recalled). On the basis of Gartman an Johnson's results, and on the basis of relate findings, it appears that varied encoding of verbal information facilitates later recall of that information, possibly because varied encoding at the time of storage multiplies the retrieval routes available at the time of recall.

Levels of Processing

Since the time the levels-of-processing framework was outlined by Craik and Lockhart (1972), the notion that retention of verbal information is governed by the level (or depth) to which it is processed has been an influential concept among cognitive psychologists. At this point in time, it no longer seems so clear as to what types of encoding operations correspond to encoding at what level. Likewise, the consequences of different encoding operations are not as clear as previously thought. Nevertheless, the general notion that greater depth of processing yields better long-term recall remains valid enough to be quite useful from a practical standpoint.

The levels-of-processing idea might be clarified by two examples. First, consider the processing that a typical human might carry out when a single common word is projected on a screen. Within a few milliseconds of the word's onset, lower-order sensory analyses of figure-ground contrast, lines, angles and so forth would take place quite automatically in the visual system, provided our typical human was looking at the screen. At some later point (i.e., milliseconds rather than seconds later) an acoustic-linguistic label for that pattern of lines and angles would be generated, also more or less automatically. Still later the subject might encode the word semantically, generate idiosyncratic or not-so-idiosyncratic associations to the word, and so forth. Such deeper levels of processing are less voluntary and more subject to variation across individuals and across time than are lower-order levels of processing. In this simple illustrative case, then, the subject might not process the word at all, might process the word only to the level of an acoustic-linguistic label, or might process the word to one of several different semantic levels. In some later situation, if the subject were asked to recall the word that had been presented, we would expect his or her recall to be a straightforward increasing function of the depth of processing actually achieved.

A second situation (in which failure to achieve more than superficial processing is painfully familiar to most of us) is the typical party setting. When we are introduced to someone, we often do not process that person's name beyond the acoustic-label level; and even then, we often do not achieve an accurate acoustic-label level; and even then, we often do not achieve an accurate acoustic representation. Under such circumstances, one's later ability to retrieve the name is usually pathetic, even after intervals as short as a minute or two. One reason we are typically so bad at processing new names at a party is that we are often in a time-sharing mode with out higher-level processing devoted to attempts to think up something clever to say, to overhear another conversation, and so forth. Even such minimal corrective measures as making sure we understand the spelling and pronounciation of a new name will help a great deal. Rehearsing new names after a minute or two has elapsed will help even more, and making a conscious effort to create a semantic structure in which to embed the name (what kind of name is it? Of whom is this person an acquaintance? What does he or she do for a living? Where does he or she live?) will reduce greatly one's failure rate. Beyond that, one can employ mnemonic systems such as those advocated in popularized books on the subject. Thus, there is a great range in the depth or level of processing we might devote to someone's name.

The levels-of-processing principle has a kind of corollary that also is quite important from a practical standpoint. There is an active-passive dimension in the processing of information by humans, and from a long-term memory standpoint, it appears that there is considerable advantage to active processing. An experiment from a dissertation by Bradford (1975) makes this point quite nicely. Bradford had subjects study sentences for later recall in one of two ways. In one condition, the sentences were presented in their normal, well-ordered form and subjects had 10 seconds to study and rehearse each sentence. In the other condition, the sentences were presented in scrambled form. The subjects had to first unscramble the sentence and then use whatever remained of the 10-second period to rehearse the sentence in its well-ordered form. One might expect that the sentences initially presented in their well-ordered form would be remembered best because subjects would have more time available for study and rehearsal of each sentences in its to-be-recalled form. In fact, Bradford found that the sentences that subjects had to unscramble were recalled better than the sentences presented in their correct form. The active processes involved in generating the sentence from the scrambled words apparently were more effective in facilitating later recall than were the more passive processes involved in reading and rehearsing a well-ordered sentence. In educational contexts as well, Wittrock (e.g., 1974) and others have demonstrated the effectiveness of such active generation processes.

The Importance of Structure

The last principle, which is certainly not independent of the other three, nor they of each other, is that "structure" facilitates both acquisition and retrieval of verbal information. Consider the following paragraph, used in a study by Bransford and Johnson (1972).

> The procedure is actually quite simple. First you arrange things into different groups depending on their makeup. Of course, one pile may be sufficient depending on how much there is to do. If you have to go somewhere else due to lack of facilities that is the next step, otherwise you are pretty well set. It is important not to overdo any particular endeavor. That is, it is better to do too few things at once than too many. In the short run this may not seem important, but complications from doing too many can easily arise. A mistake can be expensive as well. The manipulation of the appropriate mechanism should be self explanatory,...

Without being provided with a framework for encoding the foregoing passage, the passage is difficult to understand and difficult to recall. Being told in advance that the passage is about washing clothes, on the other hand, greatly facilitates one's ability to understand and recall the passage. Thus, in acquiring new information, the greater the extent to which that information can be assimilated into some pre-existing cognitive structure the better (Ausubel, 1968). Depending on the information to be acquired, such structures might be semantic, spatial, musical, mathematical, motor, or something else.

Structure is also important on the retrieval side. One may not know the capital city of every state in the union, but one's cognitive map of the United States provides a good structure on which to base a systematic effort to retrieve those we do know. Suppose, on the other hand, that we are asked to retrieve as many things as we can that are red in their typical form. Such a retrieval process is much more cumbersome, haphazard, and fallible. There is no readily available structure that one can use in searching their memory (except for certain local clusters, such as fruits). In any limited time period one would fail to access many "red" items in memory.

Mnemonic devices, such as the method of loci or the one-is-a-bun, two-is-a-shoe,... system, work because they provide a structure on which information can be "hung" during storage and out of which information can be retrieved systematically during recall. Once again, the nature of the "structure" that is involved can vary considerably across different mnemonic schemes.

Implications and Applications

The principles and phenomena outlined above have a number of implications for college instruction. Some of those implications are outlined below for each of several different aspects of the instruction process.

How to Study

The typical college student, in my opinion, studies in a highly inefficient manner. There are, of course, problems of motivation, discipline, and time management–problems that are usually the focus of the relatively simple-minded how-to-study guides commonly available to students–but I believe that even well motivated, highly disciplined students could do much better with their time. The typical student, for example, not only fails to realize that spacing one's study episodes on a given subject might be advantageous, but he or she often will go to considerable effort to block or mass the study time devoted to a particular subject. There seems to be a prevailing belief that if one's total study time falls into several different blocks of time determined by one's schedule, then each block should be devoted to massed efforts to study a single subject. The spacing effect suggests that students might achieve substantial improvements in their long-term memory for the content of a given course by simply distributing rather than massing their efforts to study that content.

The encoding variability principle also has relatively straightforward implications for how to study. Students should make an active effort to organize the content of a given course in more than one way. They should try to relate key concepts to as many different intellectual and everyday contexts as they can. The frequent refrain that one hears from individual students after an exam—"I knew the material, but not the way you asked it."—arises in part because students achieve only a kind of verbatim comprehension of course material. In order to retrieve information in the presence of a variety of different retrieval cues (i.e., to generalize), one needs to avoid having the encoding of that information confined to a specific context.

Recently, Smith, Glenberg, and Bjork (1978) have obtained evidence that encoding variability is important even when the variability is only in the physical setting in which repeated study episodes take place. Smith et al. had subjects study a list of 40 common unrelated nouns in one of two different input conditions. All subjects were given two different study sessions on the list. In the same-context condition those two sessions took place in exactly the same physical setting (a particular, distinctive room). In the different-context condition the two study sessions took place in two different (highly dissimilar) rooms. The two study sessions were separated by three hours, and three hours after the second study session subjects were given a free-recall test in a neutral context (i.e., in a room that differed from the room or rooms in which the study sessions took place).

Smith et al. found a remarkable advantage of the different-context condition over the same-context condition; an average of 24.4 words were recalled by subjects in the different-context condition, whereas an average of only 15.9 words were recalled by subjects in the same-context condition. If such results were to generalize to the kind of materials and intervals involved in the learning of course content, then students not only should distribute their study episodes for a given course across time, they also should distribute those episodes in space.

The level-of-processing principle also has an implication or two for how one should study. Students often seem to measure the amount of studying they do by how long they sit with a book or notes in front of them. Much of that time, however, is spent in superficial processing: pages are turned, but the information is encoded passively and literally at best. At worst, all higher-order processing is devoted to a personal concern of some kind with little or no processing of the written word beyond the sensory stage. Such spells are so inefficient that the student might as well have been doing something else altogether. The typical student could spend much less time studying if a higher percentage of the time spent was used more effectively.

One key to more effective processing of written material is to become more active in the processing of that material. I often tell students that there are three steps they can take to improve their memory and comprehension of course material: attend, reproduce, paraphrase. Each of these steps corresponds to a deeper level of processing. Efforts to reproduce and paraphrase are particularly effective. They constitute practice in retrieving information, practice that will greatly facilitate later efforts to recall that material on an exam or elsewhere (recognition, on the other hand, is not greatly aided by such retrieval practice; see, for example, Bjork & Geiselman, 1978).

In effect, one should input less and output more. It is curious, however, how difficult it is to get one's self to reproduce or paraphrase or summarize. Take my own case as an example; though I could hardly be more convinced of the long-term benefits of such activities, I nevertheless find them difficult to do. And students would rather spend an hour or two going over a chapter for the nth time, underlining underlined passages in a new color, than spend that time trying to summarize or paraphrase the main points in the chapter.

If one's goal is to have students process course content in a more active fashion, then there may be no better way than to involve them in the teaching process. My own efforts to involve undergraduate students in the teaching process have met with mixed success. The students involved in the teaching process regard it as a high point in their undergraduate career, but the students taking the course have a lowered impression of the value of the course.

Students could also work more effectively if they understood that some aspects of coursework require much less substantial processing than others. One should not waste ideal working conditions on superficial tasks, and one should not attempt demanding tasks in far-from-ideal conditions. Thus, there are certain activities one can do while watching a football game on the tube, and those activities should be saved for such times. An activity such as writing, on the other hand, deserves to be scheduled for the best of times in the most ideal of settings.

Finally, the importance of structure also has implications for how to study. Often students seem to acquire little in the way of an overall structural representation of the content of a given course. They memorize a series of isolated, largely unrelated facts. They are unable to draw inferences, to generalize, or to answer questions that require integration or deduction. Everyone who has taught at a college has had students come up to them and ask what they can do to perform better on the examinations in the course. Usually, these are highly motivated students who are frustrated because their exam performance is not commensurate with the amount of time they are spending on the course. They will often show you a lovely set of lecture notes and a heavily underlined textbook. In my experience, such students often lack any higher-order organization of the course content. In many cases, relatively simple remedial measures can be quite effective. Having such a student, for example, reproduce the headings and main points in each chapter of the text can often work wonders. In one such case, a student in my learning course at the University of Michigan invented a giant peg-word system on which he hung essentially the entire course content. His final exam was unsettling; it was like reading the appropriate sections out of a text.

Students also fail to build in enough structure in their notes. They record facts in succession with nothing to indicate higher-order relationships. In addition, they do not comment, they do not illustrate, and they do not paraphrase in their notes. It is a tacit assumption in colleges and universities that students know how to take notes. In general, they do not.

Course Design

The spacing effect and the encoding variability principle also have implications for the sequencing of course content. College courses are typically characterized by massing or blocking of similar topics and by a lack of repetition. From the instructor's standpoint, it seems only sensible to group related topics and it is difficult enough to cover everything once without worrying about covering anything twice. In terms of optimizing students' comprehension and long-term retention, however, spaced repetitions of important points can be very helpful (e.g., Reynolds & Glaser, 1964), particularly if such spaced repetitions are in different contexts.

I once taught an honors introduction to psychology in which an attempt was made to maximize the spaced repetition of important concepts in different contexts. Basically, I taught the course twice in one term. Up to the point of the midterm I taught a complete course based on George Miller's text, *Psychology, the Science of Mental Life,* plus several appropriate reprints. The approach in Miller's text is historical-biographical with important concepts developed in relation to the careers of key figures in psychology, such as Pavlov and Freud. During the second half of the term I taught the course over again from a physiological, brain-mechanism standpoint. I used Donald Hebb's text, *A Textbook of Psychology,* plus some appropriate offprints from *Scientific American.* (One caution to anyone who might be tempted to teach such a course: It is very difficult during the second half of the course to avoid *undesirable* repetitions of jokes or anecdotes used in the first half of the course.)

How well did the course work? Since there was no appropriate control class, I cannot say with any precision. It seemed to me that the students in the course learned more and achieved a more sophisticated attitude toward psychology than that resulting from the typical introductory course. They had one interesting and unanticipated reaction to the course. They thought that the second half of the course was great and that the first half was only fair. Had I done the obvious experiment and taught the course again with the Hebb section first and the Miller section second, I think they would still have preferred the second half of the course. There is something about having one pass over the terrain that makes one more comfortable and receptive the second time around. I remember as an undergraduate being behind all term in certain courses and then trying frantically to catch up in preparation for the final exam. I would often have the reaction in going through the material, "Hey, this stuff is pretty interesting! I ought to take this course sometime."

It is often difficult to take full advantage of the levels-of-processing principle in designing college courses. One should, clearly, design the format and requirements of the course to foster discussion, production, and discovery. In practice, however, such designs are usually a casuality of large class size.

Improved structure, however, is something that can be realized in nearly any college course. Course syllabi typically do not make the structure or rationale of the course outline as apparent as they might, nor do instructors typically spend enough time emphasizing higher-order relationships among different topics. Often such relationships are so obvious to the instructor that they do not seem worthy of comment, but they may constitute an essential (and missing) structural component from the student's standpoint.

In a recent graduate course on human memory I tried to optimize the students' acquisition of a structural representation of the course content. I ordered the topic sequence in a kind of spiral arrangement. A simple schematic flow chart of the memory system was introduced and then elaborated in successively greater detail in each of several subsequent overviews of the system. Thus, in each phase of the course, the current structural representation provided a basis for the acquisition of additional details and modifications which in turn resulted in a new, more complex representation.

It is also effective, when possible, to relate current course content to students' existing cognitive structures. With elementary school students, for example, such designs have been shown to greatly facilitate acquisition of new information. (e.g., Wittrock, Marks, & Doctorow, 1975).

The Lecture

The implications of the spacing effect and the variable-encoding principle for the design of a single lecture are much the same as those outlined above with respect to course design and how to study. The implications of the importance of structure are also much the same. Thus, one would like a given lecture to have all the properties that are desirable in terms of those three principles. The organizational structure of the lecture should be apparent, important concepts should be repeated and illustrated in more than a single context, and the lecture content, where possible, should be related to students' existing cognitive structures.

The levels-of-processing principle, on the other hand, has some implications for the lecture that merit additional comment. It is important for the instructor to realize that he or she is often confronted with a classroom full of superficial processors. Attention wanes over the lecture period, higher-level processing is devoted to other concerns, and the demands of note taking leave little or no time free for thinking and understanding. It helps, of course, to be an entertaining lecturer. It also helps to understand that 50 minutes is a very long time from the standpoint of the listener. Directing questions at the class, having the class draw inferences, encouraging discussion, are all tactics that can raise the ongoing level of processing in one's class.

The fact that a student's efforts to take complete notes can interfere with comprehension and understanding during the lecture is a real problem. Students themselves can help the problem by learning to summarize and paraphrase rather than transcribe. They then risk, however, not having complete notes available for study at a later time.

In a recent course taught by myself and John Garcia at UCLA we tried to offset the notetaking problem by making complete lecture notes available to students through the bookstore. We told the students that with the transcribing burden removed they would be free to think, to raise questions, and to write down only their own comments and observations. This step on our part met with mixed success. The most interested and highly motivated subset of students in the class liked the notes and took good advantage of them. Another large subset of the class used the notes as a basis for increasing their rate of absenteeism from the lecture.

Concluding Comments

To support my contention that recent research on human information processing has potent implications for college instruction, I have tried to show how several principles and phenomena might be applied. The principles and phenomena selected are not necessarily the best ones, nor do they suggest innovations that are altogether new in the sense of never having been thought of or tried by other psychologists and educators. The important point, I think, is that the human information-processing approach provides a characterization of the learner that is more realistic in college contexts than is the characterization provided by earlier approaches to the problem such as the stimulus-response or reinforcement-theory approaches.

As an information-processing device, the college student brings to the complex college environment an array of structures, strategies, and processes at the attentional, perceptual, and cognitive levels. He is subject to multiple, parallel demands, and those demands as well as the acquired cognitive structures he brings to a given course, influence heavily the acquisition of the "new" content in that course. All that may be obvious in a sense, but it remains a useful axiom for researchers and planners in the instruction field (see, for example, the conclusion of an excellent review of instructional psychology by Wittrock & Lumsdaine, 1977, and the concise, optimistic argument by Greeno, 1973, on the promise of research on acquired cognitive structures).

I would like to conclude by mentioning a practical problem in the transformation of research on learning and memory to college teaching. What one would like to do, of course, is to design the instruction process in such a way as to optimize the students' understanding and long-term retention of course content. Students, however, often will not be pleased with one's effort to accomplish that goal.

The kind of active, constructive processing that optimizes understanding and retention is hard work. Beyond that problem, there is a sense in which one may not always be acting in the students' immediate best interests by trying to optimize comprehension, understanding, and the ability to generalize. Research by Mayer (1975) and Mayer and Greeno (1972) suggests that while such training may indeed optimize "far transfer" (that is, performance on new problems that require a generalization from the problems involved in the training) rote, repetitive training may optimize "near transfer" (that is, performance on problems very similar to those involved in training). To the degree that our examinations constitute tests of near transfer rather than tests of far transfer, our instructional goals and evaluation procedures may be at odds with each other.

References

Ausubel, D.P. *Educational psychology: A cognitive view.* New York: Holt, Rinehart & Winston, 1968.

Bjork, R.A., & Geiselman, R.E. Constituent processes in the differentiation of items in memory. *Journal of Experimental psychology: Human Learning and Memory,* 1978, *4*, 347-361.

Bower, G.H. Stimulus sampling theory of encoding variability. In A.W. Melton & E. Martin (Eds.), *Coding processes in human memory.* Washington, D.C.: Winston, 1972. Pp. 85-123.

Bradford, E.J.F. Retention of subject-generated verbal material. (Doctoral dissertation, University of Michigan, 1975). *Dissertation Abstracts International,* 1975, *36*, 3086-B. (University Microfilms No. 75-29, 183)

Bransford, J.D., & Johnson, M.K. Contextual prerequisites for understanding: Some investigations of comprehension and recall. *Journal of Verbal Learning and Verbal Behavior,* 1972, *61*, 717-726.

Craik, F.I.M., & Lockhart, R.S. Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, 1972, *11*, 671-684.

D'Agostino, P.R. & DeRemer, P. Repetition effects as a function of rehearsal and encoding variability. *Journal of Verbal Learning and Verbal Behavior*, 1973, *12*, 108-113.

Dooling, D.J., & Lachman, R. Effects of comprehension on retention of prose. *Journal of Experimental Psychology*, 1971, *88*, 216-222.

Gartman, L.M., & Johnson, N.F. Massed versus distributed repetition of homographs: A test of the differential-encoding hypothesis. *Journal of Verbal Learning and Verbal Behavior*, 1972, *11*, 801-808.

Glenberg, A.M. Monotonic and nonmonotonic lag effects in paired-associate and recognition memory paradigms. *Journal of Verbal Learning and Verbal Behavior*, 1976, *15*, 1-15.

Greeno, J.G. Theory and practice regarding acquired cognitive structures. *Educational Psychologist*, 1973, *10*, 117-122.

Landauer, T.K. Memory without organization: Properties of a model with random storage and undirected retrieval. *Cognitive Psychology*, 1975, *1*, 495-531.

Landauer, T.K., & Ross, B.H. Can simple instructions to use spaced practice improve ability to remember a fact: An experimental test using telephone numbers. *Bulletin of the Psychonomic Society*, 1977, *10*, 215-218.

Martin, E. Stimulus meaningfulness and paired-associate transfer: An encoding variability hypothesis. *Psychological Review*, 1968, *75*, 421-441.

Mayer, R.E. Different problem-solving competencies established in learning computer programming with and without meaningful models. *Journal of Educational Psychology*, 1975, *67*, 725-734.

Mayer, R.E. & Greeno, J.G. Structural differences between learning outcomes produced by different instructional methods. *Journal of Educational Psychology*, 1972, *63*, 165-173.

Melton, A.W. The situation with respect to the spacing of repetitions and memory. *Journal of Verbal Learning and Verbal Behavior*, 1970, *9*, 596-606.

Peterson, L.R., Hillner, K., & Saltzman, D. Time between pairings and short-term retention. *Journal of Experimental Psychology*, 1962, *64*, 550-551.

Reynolds, J.H., & Glaser, R. Effects of repetition and spaced review upon retention of a complex learning task. *Journal of Educational Psychology*, 1964, *55*, 297-308.

Rothkopf, E.Z., & Coke, E.U. Repetition interval and rehearsal method in learning equivalences from written sentences. *Journal of Verbal Learning and Verbal Behavior*, 1963, *2*, 406-416.

Smith, S.M., Glenberg, A.M., & Bjork, R.A. Environmental context and human memory. *Memory and Cognition*, 1978, *6*, 342-353.

Wittrock, M.C. Learning as a generative process. *Educational Psychologist*, 1974, *11*, 87-95.

Wittrock, M.C., & Lumsdaine, A.A. Instructional psychology. In M.R. Rosenzweig and L.W. Porter (Eds.), *Annual Review of Psychology*. Palo Alto, Ca.: Annual Reviews, 1977.

Wittrock, M.C., Marks, C., & Doctorow, M. Reading as a generative process. *Journal of Educational Psychology*, 1975, *67*, 484-489.