Learning From the Top Down and the Bottom Up

Robert M. Gagné

Florida State University

To discuss human learning at the present time, you and I have to be aware of a current climate of intellectual opinion. We may agree with this prevailing trend, or we may disagree, but we have to be aware that certain lines of intellectual thought are being pursued, and that they are bound to determine how we talk about learning. Thus, for example, if we were to base our discussion of human learning on the work of Edward L. Thorndike, we should have to make interpretations of even the most elementary concepts he employed. The same may be said about more recent scholarly investigators of human learning, such as Tolman and Hull and Spence, among others. The research of all of these people has made basic and lasting contributions to an understanding of human learning. Nevertheless, to introduce their ideas into the prevailing milieu of intellectual discussion about learning would require considerable explanation.

Cognitive Learning Theory

The current climate of opinion, then, is characterized by a new kind of learning theory, or information-processing learning theory. It is represented by a number of fairly recent books, such as the series of handbooks by Estes (1975, 1976, 1978), or single volumes by Anderson (1980), Klatzky (1980), and others. Cognitive learning theory proposes the following things about human learning:

1. The fundamental unit which is learned and stored in human memory is a semantic unit; that is to say, it is inherently meaningful. Many theorists say that the basic unit which is learned and stored is a *proposition*; that is, it represents a sentence having a subject and a predicate. "Mary gave Bill a book" is an example of a fairly simple proposition.

2. How does learned material come to have this kind of organization? Is it because the external word is organized into propositions? Oh, no. The world still must be regarded as delivering patterns of physical stimulation to the learner, nothing more than that. Instead, the physical stimulation which is delivered to the senses is transformed into nervous impulses which are then best viewed as intricate masses of information. Once in the nervous system, this dynamic complex undergoes several kinds of transformation, some of them sequential, others simultaneous or parallel. Beginning with external stimulation, information is transformed at each processing stage, from receptors to sensory registers to short-term memory and to storage in long-term memory.

3. The kinds of transformation that this information undergoes are called processes, and the main concern of modern cognitive theories is with what these processes are and how they work. Probably no one really objects to calling them "mental" processes,

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although that is considered a rather old-fashioned term. Some of these processes are familiar to students of psychology, like attention, selective perception, and reinforcement. Others have attained new prominence, such as encoding, rehearsal, retrieval, and automatization. Of course, some of the old terms have taken on some new meanings. And some of the new terms are surprising if one is old enough to have experienced some of their previous history. Cognitive learning theorists sometimes speak of "conscious awareness"!

4. Besides the cognitive processes I have mentioned, a prominent part is played by what are called "control processes", or "executive control processes". These processes, as their name implies, are controlled by the learner. They are the means he has of influencing the other processes of learning. For example, if the learner wishes to "hold something in mind" for a few minutes, he may decide to bring into play the process of internal rehearsal; saying the material over to himself, internally. Rehearsal is one of the learning processes available to the learner. *Deciding to use* rehearsal is an executive control process.

5. The processing that turns external stimulation into learned information may be said to be influenced by inputs from three sources:

a. First, learning is affected by what organization or patterning is imposed on the external stimulus. What form does instruction take when it is presented? Are the names of the states presented on a map, or in an alphabetical list? Is an account of the Great Depression of 1930 presented in a text which contains topic headings and italics, or in continuous prose without such features? Is the addition of positive and negative numbers presented by means of a number line, or by verbal rule statements?

b. Second, learning is influenced by the executive control processes available to, and used by, the learner. The names of states may be elaborated by a control process which imposes some sort of mnemonic system. The rules for adding positive and negative numbers may be recalled and used by means of a particular strategy that sorts out the different adding and subtracting operations appropriate for like and unlike signs.

c. Third, and by no means least in importance, learning is affected by the contents of memory–in other words, by what has previously been learned. The events of the Great Depression will be learned and stored most expeditiously when the learner can recall previously acquired knowledge about the market system, about money and banking, about jobs and employment. The names of states will best be learned and recalled if they are linked to other previously learned information about them, such as their locations on a map, their shapes, their distinctive economies or cultural features. And most obviously of all, the rules for adding positive and negative numbers will be most efficiently learned when the learner is able to retrieve in working memory the previously learned intellectual skills of adding, subtracting, and compensating increases with decreases.

Summarizing these points, modern cognitive learning theory proposes that learning and remembering are brought about by internal processes which are affected by the external organization of stimuli, by control processes brought to bear by the learner, and by the contents of the learner's memory.

Computer Technology

There is another important aspect of today's *Zeitgeist* which must be taken into account when discussing learning. This is the applied technology provided by the computer, and particularly by the microcomputers now becoming available. These computers, together with linked hardware such as the video-disc, are available now and will become increasingly available at lower cost in the near future. What will they do for human learning in the practical sense? We cannot, I think, suppose that they will die away as did the last flurry of interest in computer-aided instruction twelve or more years ago. We are going to have instruction via computers, it would seem, whether we like it or not. Computers with instruction are going to invade the home, and they will likely also truly invade the classroom.

I can remember when computer-aided instruction was beginning to appear, perhaps fifteen years ago, the sequences of instruction presented were more or less like "teaching machine" programs. What the computer appeared to be doing was "turning pages"; a question would be asked, the learner would type in an answer, the computer would indicate the correctness of the answer, and proceed to present another question. We tended to scoff at this menial page-turning task the computer was performing–surely this was not the sort of thing such an expensive piece of hardware should do. In fact that is what some of the main forms of computer instruction have been like over all the intervening years, and what they are still like today. Yet, the computer remains a highly intriguing way of presenting instructional content, and of taking some account of the learner's responses to that content. Maybe learners simply prefer to look at screens rather than pages. Maybe they like the pressing of keys as a kind of concrete action that is not demanded by a page of printed text. Maybe the reassurance of a visual mesage displaying an answer to a question is inherently more pleasing than looking up the answer on a printed page.

Whatever may be the case, we necessarily have to conduct a discussion of human learning against a backdrop of realization that much learning may be done in the future by computer controlled devices, and also by thematic story-telling programs such as those we see on public television. The model of the teacher "delivering" organized instruction to students, regardless of its effectiveness, is not likely to remain as a standard. At least, it will have to be modified in many ways. Educational researchers have often spoken about the teacher as a manager of instruction, as opposed simply to a communicator. Managing instruction seems likely to be the mode of the future, to an increasing degree and in many new dimensions.

These two aspects of the current scene bearing upon education cannot give us unambiguous signals of the advantages of top-down or bottom-up learning. Both of these approaches, which I am about to describe more fully, can be accommodated by cognitive learning theory and also by computer or video-based instruction. Nevertheless, it is within a framework that takes both these trends into account that we must consider how to arrive at a suitable decision about conditions designed to promote learning.

Top-Down Learning

The advocates of top-down learning generally hold the point of view that a primary aim of education is to teach students to think. In the post-Sputnik era, this idea became very popular. This was particularly true as scientists and mathematicians came to wield their very considerable influence over the design of curricula and the accompanying efforts of teacher education.

Several themes made up the trend which emphasized thinking and problem solving as primary goals, and almost exclusive goals, of education in grades K through 12. Some of the main ideas may be identified as follows:

1. Much of public education was said to be composed of dull, repetitious, pedestrian tasks such as the committing of facts to memory.

2. New curricula were required, not just to bring the facts up to date, but to reflect and teach the rational processes engaged in by scientists and mathematicians. In other words, it was not enough to teach the concepts of math–one should have students derive the concepts of math (the new mathematics). Similarly, it was not sufficient to teach the principles of physics–one should encourage students to derive the principles of physics (PSSC Physics). Thus, this line of thinking led to the development of curricula which were intellectually very demanding. One strand of "top-down" learning results in some curricula which were difficult for many students.

3. The third prominent strand to the top-down movement was the concept of "discovery learning". This was championed by Bruner (1961) in some of his writings, and also by many scientistists and mathematicians. In science instruction, it might be called "inquiry". While this term had a broader meaning, it nevertheless included the essential elements of discovery. In its simplest form, discovery learning was supposed to occur when several specific examples of a concept or principle were presented in the learner's environment, and she was expected to "discover" the general principles. In one of Bruner's examples, individual learners were presented with a bar to be balanced on a fulcrum; they had access to a number of unit weights which could be hung on the bar at several different distances from the fulcrum. By trying various combinations of distances and weights, the learner was to discover the general principle about moments of force and equilibrium. In a more general sense, the learner was encouraged to discover a solution to a puzzling problem, rather than being told how to solve it.

4. On the whole, the conduct of top-down learning was considered to accomplish some very desirable educational outcomes. For one thing, it would produce students who were better able to think, because they had had practice in thinking about a variety of novel problems. This kind of experience would, it was thought, produce students who tackled challenging problems in highly original ways. They would develop a love of learning because, freed of the repetitiousness and dryness of memorized facts, they would enjoy the experience of finding their own solutions to problems. Over a period of time, they would develop great confidence in their ability to learn and to solve problems.

These are some of the ideas about top-down learning that have been current for forty years or so. I am not sure where they came from. Each one of the ideas, separately, may be seen to have had a rational basis, in the sense that each of them is a reasonable hypothesis. They were not, however, based upon empirical findings–that is quite clear. The deleterious effects of memorizing facts have not been demonstrated. The advantages of acquiring a derivational for mathematics or physics have not become evident. Discovery learning, as studied in the psychology laboratory, appears to have at most a very narrow base of advantageousness, and not the highly generalizable effects its advocates would like to see. Evidence is entirely lacking that students who have experienced curricula and teaching which encourages discovery turn out to be better thinkers. It is, of course, hard to get such evidence, positive or negative.

Recent developments. The ideas of top-down learning now appear in new forms, influenced both by cognitive learning theory and by the prospects of computer-based instruction. For example, the kind of analysis of problem solving reflected in the book *Human Problem Solving*, by Newell and Simon (1972) has led to a number of investigations of problem solving in children and adults. Such problems as chess, the Tower of Hanoi, cryptarithmetic, and problems of algebra and arithmetic, among others, have been intensively investigated. The main point of many of these studies is that of identifying and verifying the processes used by people in solving such problems. Having done this, the further effort may be made of designing and teaching a course in problem solving (Hayes, 1976). The conception of cognitive learning theory that runs through these studies is the notion of *cognitive strategies*, those skills by means of which the human learner controls his own learning and thinking processes. These are executive control processes. Obviously, that is a top-down conception.

Other efforts to explore cognitive strategies have been carried out by scientists and science education researchers. Often, these studies are cast in the mode of Piaget's ideas, so that what is investigated is the transition from concrete to formal operations (Karplus, Karplus & Wollman, 1974; Lawson & Renner, 1975). Some evidence has been obtained to indicate that direct teaching of scientific reasoning can be done with some success (Lawson & Wollman, 1976). However, the generalizability of what is learned is not known. Issues involved in these studies of science and mathematics education are discussed in a book by Tuma & Reif, *Problem Solving and Education* (1980). The main issue being addressed by these investigators is whether or not students can be directly taught to think.

Can cognitive strategies of learning and thinking be taught? The answer is clearly yes. There are in fact many examples of successful teaching of relatively simple strategies of remembering, such as rehearsal and classification, in young children (Brown, 1978). As for problem solving, the evidence runs somewhat as follows. Specific problems, besides calling upon knowledge and skills, also involve one or more cognitive strategies for their solution. Strategies may be relatively simple and concrete (like counting) or they may be quite complex and abstract (like seeking contradictions). If they are already known, they may be activated by the learner or by verbal instructions (Gagne, 1980).

There is, then, a current trend in top-down learning which proposes to teach thinking directly. The hidden agenda in such studies, so far as their ultimate application is concerned, is "let us try to skip over all the basic intellectual skills, and just teach children how to think". There remain differences of opinion, however, as to the prospects for successful outcomes of such instruction. Simon (1980), for example, is quite optimistic about the general usefulness of such strategies as means-end analysis, while Greeno (1978) is much less sure that the specific strategies of problem-solving will generalize. At the same time, virtually all investigators of thinking find themselves forced to include the idea of *essential prerequisites*. Regardless of the success that may be had in teaching techniques of thinking, verbal knowledge and intellectual skills enter into the solution of concrete problems.

Computer-based learning. Some proposals for top-down learning involve the use of the computer. Traditional computer-aided instruction has taken the form of drill and practice, and some success has been attained with this mode of instruction. At the same time, it has been possible to use the computer to present simulated problem situations, and these are also successful for the instruction of suitable capable learners.

For some years, though, there have been those who have continued to think that the computer could teach in a *tutoring mode*–that is, a mode in which the individual responses of the learner are taken into account in the presentation of the next following question, or other display.

A mode of top-down learning as involved in Socratic tutoring has been explored and described by Allan Collins (1977). He has been able to design and test a computer program which asks the student a succession of questions dependent upon the answers she makes. Collins describes a set of 24 rules built into the computer program which enable it to conduct a Socratic dialogue with the student. For example, Rule 1, at the start of the dialogue, is "Ask about a known case", and here the computer asks the student about an instance that she probably knows. When the dialogue refers to the factors affecting the growing of rice, the question may be "Do they grow rice in China?" The dialogue proceeds, with rules governing the presentation of examples, counterexamples, generalizations, and so on. For example, the next question may ask the student where rice may be grown in North America.

There are, of course, other kinds of approaches to top-down learning using the computer. Clearly, though, this effort at a Socratic dialogue is one good example illustrating both the possibilities of such learning and the constraints under which it may occur. It is the characteristic of the Socratic method that by clever questioning the learner may be stimulated to carry out inferential thought that leads to new knowledge. Surely if one assumes there are suitably prepared high school students (who know, for example, where low-lying flooded areas occur in the United States), one can suppose that a considerable amount of new knowledge can be generated by this technique. At the same time, the necessity for the pre-existence of relevant knowledge in the learner's memory is quite apparent.

Bottom-Up Learning

Perhaps it will be apparent to those who know my writings that I have always tended to emphasize bottom-up learning, while not denying a degree of importance to the top-down variety. In these days, I am continually impressed with the wide prevalence of "remedial education", in the elementary and junior high schools, in high schools, in colleges and universities. When remedial education is found to be necessary, it is typically the case that some basic skill or set of skills has not been learned. When remedial students initially tackle problems in subtraction, multiplication, or other basic math operations, they typically perform them in accordance with rules they have picked up, or perhaps devised themselves, which are simply the wrong rules. For example, students multiplying two-place numbers may perform the operation in a number of ways which are entirely consistent and rule-governed, although nevertheless wrong (Resnick & Ford, 1981). They have not learned the correct rules, and since their own way of doing things works partially and on some occasions, they persist in doing these simple operations wrongly. It seems to me that studies of students who are in this fix show very clearly that they must learn correctly the very basic skills they should have learned years ago. I do not suppose that is easy to do, and it obviously requires some specially designed instruction. But *what* must be learned is quite clear.

Although there are fewer studies of poor readers in need of remediation, those that do exist tell much the same story. There are three principal areas of skill involved in reading, speaking for the moment of "literal comprehension of text". These three areas of skill are, first, decoding; second, printed word recognition; and third, sentence construction. These are the basic skills usually found missing in poor readers. One would suppose they should have been learned at the latest by Grade 3. If poor readers are going to become good readers, it is these basic skills that somehow must be learned. Again, if students are already in the 10th grade when reading deficiencies are detected, I realize that one cannot proceed by using 3rd-grade primers. Nevertheless, it seems clear from the evidence that these skills that must be learned.

It seems fairly evident that when remedial education is undertaken, learning is definitely bottom-up. It is basic, prerequisite skills and knowledge that must be learned, and one cannot depend on previously learned knowledge as a dependable link to what must be newly learned. Why not? Because, as I have mentioned, what has been learned is wrong–incorrect–non-useful. It must be ignored as a part of the learner's repertoire that can contribute positively to new learning.

Can remedial instruction be done by top-down methods? The idea that it can seems to me to be quite irrational. Yet there are those who advocate such a course of action. More often than I like, I encounter articles which advocate things like teaching mathematics derivatively from the properties of numbers, or teaching problem solving, or teaching formal thinking, as solutions to the problem of remedial education. In English writing, this advocacy is likely to take the form of a plea for teaching creative writing–ignoring the fact that the students can't turn out a complete sentence. In reading, one finds this "top-down" attitude in the emphasis on reading comprehension. The argument is, it doesn't matter whether the student can read individual words–after all, what we are aiming for is *comprehension.*

I believe that all these ideas are fundamentally irrational and baseless. Basic skills are basic skills. When students can't perform in mathematics and in language, they are missing some basic skills. How else could these possibly be learned except from the bottom-up?

Turning from remedial education or ordinary education, there is plenty of evidence that the learning of complex intellectual skills depends on the prior learning of prerequisite skills. The learning hierarchies that I worked on in the areas of arithmetic and algebra have been followed by other studies in other areas such as those of science; for example, acceleration and force in an inclined plane, interpretation of position-time graphs, voltage in electric circuits, and others (White & Gagne, 1974). I wish there were equally good evidence of the casual effects of prerequisite skills in reading, but such is not the case. Experimental research in reading is not easy to do. However, the correlational studies that exist clearly show the close relations of the basic skills I have mentioned to reading, including measures of reading comprehension.

Some implications of cognitive learning theory. What does cognitive learning theory have to say about bottom-up learning? Learning theory is in fact beginning to say some very important things in this area (cf. Anderson, 1980; Bower & Hilgard, 1981). Let me try to summarize a line of reasoning I detect.

1. Performing complex tasks, like solving word problems in arithmetic, or gaining information by reading text, or composing an essay, usually requires some parallel processing of information in the working memory. Some of the information comes from outside the learner, some from his long-term memory store, but tasks often demand some simultaneous processing of information, if performance is to be successful.

2. The working memory has a limited capacity. A limited number of items may be held in its focus for a limited amount of time. This means that processing of this information also has limitations in what can be done all at once. The cognitive resource called attention must be brought to bear on novel tasks. The individual must use his attention sparingly and efficiently.

3. It is possible for the learner to carry out several processes simultaneously because some of them require a minimum of attention. These cognitive operations have been automatized–they have become automatic. It is interesting to have this old idea of automaticity re-introduced into prominence in learning theory.

4. Mental operations become automatic when they are practiced over and over again. Although there are theorists who are interested in what the nature of the change from non-automaticity to automaticity may be, none has as yet suggested any way of achieving automaticity except by *practice.*

What implications do these ideas have for bottom-up learning? Some important ones. For example, the most widely held theory of reading, among cognitive psychologists, is that certain fundamental skills must be automatized, in order for reading comprehension to proceed efficiently and without hesitation. Thus, the view is that such basic skills as decoding, and also printed word recognition, and sentence structuring, need to be practiced until they attain automaticity. Then the processes required for reading comprehension (the "thinking" processes that E. L. Thorndike talked about) can go forward without restraint and without interruption.

Now if we take these ideas seriously, their implications are profound. They tell us not only that we need to go back to basics–we also need to go back to drill and practice in these basics! If reading comprehension can best proceed when certain skills have attained automaticity, then these skills must be practiced consistently until they become automatic. That implies a criterion greater than simply "learning", and greater even than "mastery". Automaticity is the watchword for fundamental skills.

Although the case has not been made in quite the same way for the activity of writing, I cannot see why different conditions should prevail. Fundamental to good writing are the skills of making adequate sentences, using topic sentences, making good paragraphs, providing transitional cues for the reader. Again the argument is, only when these skills become automatic can the mental processing required for creative writing be brought into play without hindrance. And, again, we are reminded that this kind of learning demands the bottom-up treatment of continued and varied practice.

What about mathematics? Again, the same principle will undoubtedly apply. Performing novel and complex problems in mathematics can best occur if fundamental skills have not only been learned, but also learned to the point of automaticity. Examples of the kinds of mathematical operations that would best be automatic are these:

$$7/15 \div 3/5 = 7/15 \times 5/3$$
$$^{-}7 + {}^{+}3 = {}^{-}4$$
$$(x - 1) = (x + 1)(x - 1)$$

However these rules are used in solving problems, it is best for them to be processed automatically. When that can be done, according to theory, attentional resources will be available for thinking–for performing the kinds of novel mental processing demanded by novel problems.

Computer-based instruction. Consider again what the computer offers along the lines of making skills automatic by practice. Just the thing! Whether we think of it as mere page-turning or not, the computer is known to have infinite patience, much more than that of most human teachers. The computer can present a virtually endless succession of examples of rule application, or concept identification, so that the learner can practice the same intellectual skill over a long period of time, should that be necessary. Successful use has been made of this kind of computer instruction as an adjunct to regular instruction in the elementary grades, in the fields of reading and arithmetic. Quite probably, the computer can be used effectively to provide the practice that leads to automaticity. Perhaps that is the best use of the computer in the elementary grades, or until fundamental skills become automatic. If it turns out to be desirable and useful, Socratic tutoring can come later.

Concluding Statement

Learning from the top-down continues to be a highly appealing option for many who think about school instruction. Whether such an approach to learning takes the form of student-derived science, of discovery learning, or of Socratic tutoring, it is usually not difficult to show that such instruction works. Provided one has chosen the proper students, top-down learning will work in the sense that what are stated as the objectives of its content will be learned. Usually, too, what is learned by this method is acquired with a good will and with some pleasure. How generally the knowledge, skills, and startegies learned in this manner can be used in new and different situations is still an open question, concerning which no pre-judgment can be made.

The practical aspects of top-down learning, however, present some difficulties. When studies are done to discover what makes a difference in the effectiveness of top-down learning, they repeatedly come up with the finding that what distinguishes good from poor learners is the presence of *a relevant store of prerequisite skills*. How are these prerequisite skills to be learned? Can they, too, be learned by top-down learning? Well, of course, they *can* be, but it is doubtful that they usually are. The chicken-egg problem of top-down versus bottom-up does not seem very puzzling. Bottom-up learning must provide the basic stored items in the learner's memory that make top-down learning possible.

According to contemporary cognitive learning theory, there is an even stronger reason for a resort to bottom-up learning. Problem solving uses limited attentional resources, and requires that certain intellectual processes be carried out in parallel. These cognitive resources can be economically allocated if some kinds of processing can be done automatically. Many intellectual skills can be practiced until automatization occurs. According to current views of such basic subjects as reading, writing, and arithmetic, many of their fundamental skills *should* become automatic, which means they must be practiced far beyond the point of being barely learned. If we truly value top-down learning, we should perhaps try to find ways of restoring drill and practice to the elementary grades. If teachers won't do it, perhaps computers will.

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