What Goes on in the Mind of the Learner

Donald A. Norman

What goes on in the mind of the learner? This is a question that has bothered me for several years. I have been trying to understand how students learn complex materials, how they acquire the knowledge of complex tasks. I have spent tens of hours watching students, sometimes questioning them about each sentence or paragraph they have read, sometimes cajoling them to think aloud as they progress through instruction manuals, sometimes remaining silent but simply observing their progress. I have tried manipulating the way in which the material is taught, the structure of the instruction manual, the instructional aid that is presented. My conclusion is that a lot goes on within the student.

Let me warn you that I have studied a very special set of students under a very special set of circumstances. My colleagues and I usually spend two hours or so in a small experimental room with each student, watching the learning of a relatively complex task. The students have several learning tools available. For thirty minutes prior to the learning situation, they may have been tutored on the topic and may have participated in a "role playing" game designed to help them understand the task. They were given instruction manuals for the tasks, written specifically to help beginning students. The students actually did the tasks while reading the manual, following all the best tradition of "learning by doing" or "exploratory learning." And at times, a sophisticated computer-controlled instructional system watched over the progress and offered advice whenever it seemed needed. We explained to the students that our goal was not to teach but to learn. I wanted to watch the student attempt to learn the material, so that I would be able to understand how useful the instructional aids actually were, to sense the nature of the difficulties that were encountered, and to note those spots where there were no problems—where learning proceeded smoothly.

Although I believe that I have gotten at some of the important issues of learning, I admit freely that I may have missed other issues, perhaps just as important. For one thing, I have studied a very limited set of topics, and it is an open question whether my observations really generalize to all topics. For another, I continually interfered with the learning process, and my subjects know they are in an experimental situation, that neither their grade in a course nor an evaluation depends upon the results. Finally, I have studied only a small group of subjects who are typically well motivated for the tasks (after all, they have volunteered to do a "learning experiment" and are getting paid in money or class credit for their performance). Thus, many of the real file variables that have major impact upon classroom learning are absent from my studies. But I have found major problems in the learning process nonetheless. If problems exist under these idealized conditions, what must normally occur?

A Model of Learning

For years I have been concerned with the study of memory. More specifically, I have been concerned with the study of how knowledge is acquired, maintained, and retrieved. A major problem has been the understanding of the representation of knowledge within the human mind. What is learning if it is not the acquisition of knowledge? A complete theory of memory therefore includes a theory of learning. The basic theory is really quite simple. Figure 1 shows a very rough schematic diagram of knowledge. All those brackets, pointed arrows, and ovals represent the knowledge within someone's memory structure. Note that there is a gap. Learning, according to this point of view, is the filling in of that gap, first, perhaps, by acquiring a missing piece, then by neatly knitting the piece into the existing network of knowledge. All this is illustrated in the figure.

According to this point of view, in order to teach, one must have knowledge of the topic that is to be taught, plus an understanding of the knowledge that the student already possesses. Then, one simply teaches the differences between them. It is actually rather simple, somewhat like building a house. First you obtain a blueprint or plan for the final structure. Next, you lay out the foundation and the scaffolding. Finally, the house gets erected upon these basics.

To illustrate how we actually go about doing this, look at Figure 2. Here is a partial data base of knowledge about the Civil War: it deals only with events of the Western campaign in the early days of the War. The theory suggests that to
understand any given topic matter, one simply has to understand the representation of that topic, know about the student's gaps in knowledge and selectively present the missing parts. There are many problems in deciding what material should be taught first, and indeed in previous publications I have worried considerably about the proper ordering of the material to be taught (Norman, 1973, 1976). I advocated a form of "web teaching," a procedure wherein one first establishes a coarse "web" of concepts, teaching the overall highlights. Then, one goes back and fills in some of the details. Then one repeats with more details and continues going back over the framework, making it tighter each time until all the knowledge is at the desired density level.

Learning is really very simple, according to this point of view. Teaching is relatively simple, also. All one has to worry about is a proper understanding of the knowledge and of the student, and proper selection of the order of presentation.

Unfortunately, it does not work that way. I wrote simple textbooks. I devised teaching procedures. I watched student after student learn. If only I could write the perfect text, students would whiz through it. If only the text would match the student's knowledge, then the student would read each page in turn, and would slowly accumulate the appropriate knowledge, in the appropriate manner, with the appropriate level of understanding. But I found that the student waivers, skips ahead, jumps back. Pages get reread. Whole sections get revisited. Why?

What was wrong was the simple theory of learning. Essentially, I had assumed that students were passive receptors and that an ideal teaching situation would be one where the students would come into the classroom, unscrew the top of their skulls, and the instructor could walk around the class, peer intently into the brain of each student and say something like, "Hmm, you seem to have this connection missing," and then proceed to add the necessary connections. What a lovely vision!

But students are not passive receptors of knowledge. Although I do not yet understand the specific way by which new knowledge is acquired, it does involve active interpretation on the part of the student. The student comes to the learning situation with a large set of preexisting ideas, and the material that is presented is interpreted according to these ideas. You cannot prevent it; I have tried. I have tried to present material in a neutral fashion. I have tried methods of discovery learning, in which the student interacts with the task, discovering the important principles of the day. I have carefully worked to set up the task so that the "discovery" leaps out and waves itself in the student's face. Well, sure the student will interact, and sure the student will discover things. But what is discovered and how it is interpreted is up to the student, and sometimes I feel I have remarkably little control over the process.

Learning as Theory Building

What goes on in the mind of the learner? A lot: People who are learning are active, probing, constructing. People appear to have a strong desire to understand. The problem is that people will go to great lengths to understand, constructing frameworks, constructing explanations, constructing huge edifices to account for what they have experienced.

A learner is something like a theorist, building an explanation of what has been seen. But, like a theorist, a learner builds on incomplete evidence, tends to ignore information that does not fit, and will grasp at any evidence that can serve as confirmation. It is often surprising what learners come to believe. You would not believe how many learners ignore critical material when it does not make sense. I find also that learners take it for granted that they will not understand all that is presented to them. They casually skip over huge aspects of their material. Don't you? Do you really read every sentence of the instruction manual that accompanies the new calculator, or television game, or appliance? Most of us have no qualms whatsoever about skipping huge amounts of material. After all, if it really is important, it will show up again.

Students seem incredibly willing to ignore discrepancies in their knowledge, to ignore sentences (paragraphs, pages, chapters) that they do not understand. We have even discovered bad errors in the instructional material that stayed around for a considerable time because students calmly read the material and went on, never bothering to tell us. This was despite the fact that we encouraged questions, that I often was sitting next to the student the whole time, encouraging the student to think aloud, and despite the fact that the discrepant material was contradictory to what had already been learned.

On the other hand, material that we believe to be especially clear, or well prepared, often poses insurmountable difficulty to students. They will stop and ponder, do exactly the wrong thing, fail to follow the instructions, and drive us to distraction. As a dissertation from my laboratory indicates (Bott, 1973), at the sections where the instructor believes things are self-evident, there is a strong tendency to leave much unsaid in the instructional material. The student, therefore, is forced to fill in all of the appropriate background material, and in this process there is a great chance for erroneous construction.

It is the student who decides what aspects of the material are important, what aspects are not. The student is essentially making up a story, and if the course material is not explicit enough, the student's story is apt to deviate considerably from what the instructor intended. But, because the student's story must be consistent with the course material, it is often an accurate characterization of what has been seen so far, and often it allows for consistent continued performance with new material. All this despite the fact that the structure is erroneous. This can lead to disaster, for when the student eventually has difficulties with the material, it may be at a spot far removed from the cause.

We have come to call this phenomenon "the Iceberg Model." The iceberg, you may recall, has a small part visible above the water, and the bulk of its structure hidden beneath the surface. This model can be interpreted in two ways. From the point of view of the learner, the part of the iceberg that is above the surface of the water is the material that is presented. The learner must then determine what the underlying structure might be. From the point of view of the teacher, the behavior of the student is like the part of the iceberg that is visible. The student has erected a huge structure, and if the teacher is to understand the difficulties eventually faced by the student, this structure must somehow be uncovered.

Learning from Prototype Models

Examination of the way in which our subjects learn indicates that they build upon previous structures.
Let Part A be a schematic diagram of knowledge in the head. The oval, brackets, and arrows reflect the interrelationships and forms of knowledge. Note that there is a hole in the knowledge. In Part B of the Figure, a new set of relationships have been entered: C1 is related to C2 by means of the relationship R. This new knowledge is unrelated to anything else, however, and so before it can be adequately used or accessed, it must become interwoven into the network of prior knowledge. This is shown in Part C of the Figure, where the new knowledge has become interconnected appropriately with the prior knowledge, so well that it is no longer possible to distinguish the new from the old. When done properly, this is what I would call "web learning."

This is meant to illustrate some of the knowledge that a person could acquire about the Western campaign of the American Civil War. The notation follows that of Norman, Rumelhart, and the LNR Research Group (1975). However, you need not understand the details of this representation, but rather simply note the extensive amount of knowledge that is required, even for this rather simple part of the database. To give an example, however, of the information being encoded, let me express in words the part of the database shown in the upper right-hand part of the figure (the part near the label "Western campaign"). "The desire of the North to disrupt the internal transportation of the South" motivated a set of actions. These are that because the North believed that the situation of the location of the Mississippi River allowed the event that if the North would take the Mississippi River that would cause the disruption of the internal transportation of the South. All of this motivated the desire for the North to take the Mississippi River, and this led to a series of actions based around Cairo, Illinois."
Figure 3. Example of Oversimplified Map

A

Ohio River
- Ft. Donelson
- Ft. Henry
- Cumberland River

Tennessee River

Shiloh

Vicksburg

Washington
- Richmond

Mountains

New Orleans

B

Cairo
- Ft. Donelson
- Ft. Henry
- Shiloh

Vicksburg
- New Orleans

Northern Blockade

Northern Ships

This is an oversimplified, but very useful map of the southeastern part of the United States. None of the details is correct, yet this map is superior to real maps for illustrating the importance of geographical features on the conduct of the War. Part A illustrates the major aspects of geography and of railroad routes. Part B illustrates the major northern strategy, that of attacking from the north from Cairo, Illinois to take the northern part of the Mississippi River, that of blockading the cities along the eastern and southeastern coasts of the United States, and then attacking the Mississippi River through New Orleans and, finally, Vicksburg. In addition, Fort Donelson and Fort Henry on the Cumberland and Tennessee Rivers were captured in order to prevent river traffic. Shiloh, an important rail and river city, also played a major role in these early battles of the War.
Essentially, they tend to learn by analogy. This is learning from a prototype model. In order to understand the topic, you have to be able to relate it to other things that you know. It makes sense that the relation should be made by taking some already existing knowledge and adapting it to the new situation. The common problem we find is that students like to interpret current knowledge in terms of old knowledge, but often the interpretation is not the one that is most useful. Making interpretations like this can be very powerful. It allows one to make predictions about the situation. It allows rich expectations, even in the absence of full knowledge. It is the standard procedure used in theories of cognitive psychology and working programs of artificial intelligence. The deficits are that it leads to a closed mind, that it can lead to false expectations and, unless the prototype model is chosen properly, that the new knowledge may not fit the structure being built. A discussion of some of the ways in which people use conceptual models in learning can be found in Stevens and Collins (1980) and in VanLehn and Brown (1980). In our own work, we found it essential to provide the prototype model for the student. If you as a teacher do not provide the model, the student is likely to pick one anyway, and if you are to have any control in the situation, it is best for you to have made the selection.

The choice of the model is critical. Thus you should make sure that your students understand the prototype. It does little good to explain topic A in terms of topic B if the student does not understand topic B. I am coauthor of an introductory textbook on psychology (Lindsay and Norman, 1977) in which we cleverly taught the psychology of sound through the use of music as the prototype model. We used musical notation and musical illustration. For some students, it really helped. But for many students, we made life twice as difficult. These students did not understand music, so for them we were explaining one poorly understood topic with the aid of another poorly understood topic. The teacher must be concerned with selecting a prototype that suits the learner.

It may be easier to find a prototype model that matches closely the characteristics of the task or topic to be learned. Thus, Stevens and Collins (1980) discuss different conceptual models students have for an understanding of rainfall. The student models are often incomplete, gross simplifications of the real situation. If the simplifications are not carefully selected, they lead to erroneou predictions. Does it rain more in Oregon than in Idaho? If we were suddenly to construct a new continent between Europe and the United States, would it be rainy on its East Coast or its West Coast? To be able to answer questions like these, the student needs to have a good conceptual underpinning.

We have found that it is sometimes useful to use several models, each model serving a different purpose. Thus, in teaching the operation of a computer text edition (a computer program that makes it easy to type a manuscript and then make editorial changes and rearrangements in it, without retyping the entire text), we have found it useful to use three different prototype models. The three different models are of a secretary, a tape recorder, and a card file.

The model of a secretary depicts a person willing and eager to take down the text of a manuscript. The secretary can follow instructions and can make corrections to the manuscript. The secretary prototype is an excellent model for the overall conceptualization of the task, but it leads to difficulties in several different situations. For example, the secretary model does not specify on what kind of material the text is written, and so the student is forced to make some decision, which usually leads to later misunderstandings. Perhaps more important, however, a secretary can distinguish between comments that are meant to be part of the manuscript and comments which are instructions about how to prepare the manuscript. This confusion leads to some serious errors in the use of computer text editors.

A second conceptual model which we use is that of a tape recorder. Here, the model specifically is useful for one point: when a tape recorder has been put into "record mode" everything that is said from then on will be recorded, and the tape recorder cannot tell when a comment was meant to be an aside. The only way to stop the tape recorder from recording what has been said is to take specific action: to depress the "stop" button. This turns cut to be an excellent model for understanding the edit procedure from the append mode of a text editor. The tape recorder model has problems, however, especially when it comes to the deletion of material. If deletion is thought of as erasing, then there is the awkward problem that a blank tape remains in place of the message.

The third model we use is that of a stack of three-by-five cards. Each sentence of the manuscript is typed on a separate card. This card file model explicitly yields an understanding of the storage of the text and makes it easy to understand the delete and insert commands. This prototype model, however, has difficulties with other aspects of the editor.

We find it necessary to teach by the use of different models for different purposes. The student is introduced to each model and informed of its strengths and weaknesses. A similar story can be told about our studies of the American Civil War. In teaching the geography of the United States relevant to the Civil War, we found it essential to oversimplify the map. The real map of the United States is much too rich, it contains excess information, and the student is usually not capable of extracting what we consider to be the important essentials. Figure 3 shows the type of oversimplified map that we use. The virtue of this prototype model is that it brings to the fore-ground the important features of the geography. The map is distorted and sketchy. However, the oversimplification is obvious, and so it need not lead to later confusion on the part of the student.

Accretion, Structuring, and Tuning

Learning is not a unitary activity. There is much going on. My colleagues and I have found it useful to speak of at least three different stages: accretion, structuring, and tuning (Rumelhart and Norman, 1978). Accretion is the accumulation of knowledge into already established structures. Structuring is the forming of the right conceptual structures—and has been the major topic of this chapter until now. Tuning is the making efficient of this knowledge—making it possible to go from the stumbling, struggling state of the novice to the smooth, practiced skill of the expert.

It is not enough to understand the topic matter. Once you have learned the topic, it must be used. It must be practiced. It must be "tuned" so that its use becomes effortless. It must become available without mental effort. How long does this take? A long time. I have estimated that something like five thousand hours are required to become an expert on any topic. Five thousand hours is two years of work, forty hours a week. Think about multiplication. It is one thing to understand the principle of multiplication. But if the tables are not understood thoroughly, if they have not
become automated, then when one solves a multiplication problem, the problem of computation will be overwhelming. Understanding is not enough to get through life, you need to have complete automaticity of the fundamentals of the topic.

Let us return to basics, because mental abilities are limited. Our ability to think is severely limited by the size of our short-term memory. Basic fundamental aspects of any topic matter must come automatically, without the need to use up valuable mental resources. And so far as I can tell, automaticity comes only through repeated use and practice.

Conclusions

Much goes on in the mind of the learner. Students interpret. They overinterpret. They actively struggle to impose meaning and structure upon new material being presented. To do this, they appear to use a prototype model on which to base future learning. It is something like an iceberg, with the student providing a huge substructure to account for the small visible parts of the topic matter.

In teaching, it seems best that the instructor provide the prototype models. If the instructor does not do it, the student will, and the student’s models are apt to be less fitted for the topic than the instructor’s. Different prototypes are needed for different purposes. Each prototype will have strengths and weaknesses. The use of inappropriate prototypes can lead to peril, since the use of a prototype appropriate for one aspect of the task may lead to difficulties in other aspects, unless this is carefully demonstrated to the student.

What goes on in the mind of the learner? More than you might realize; more than you might wish.

References